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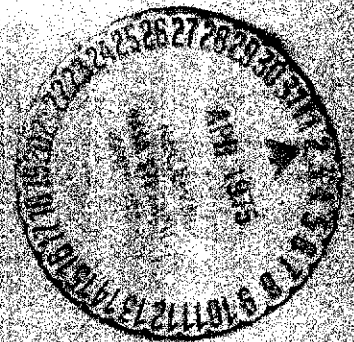
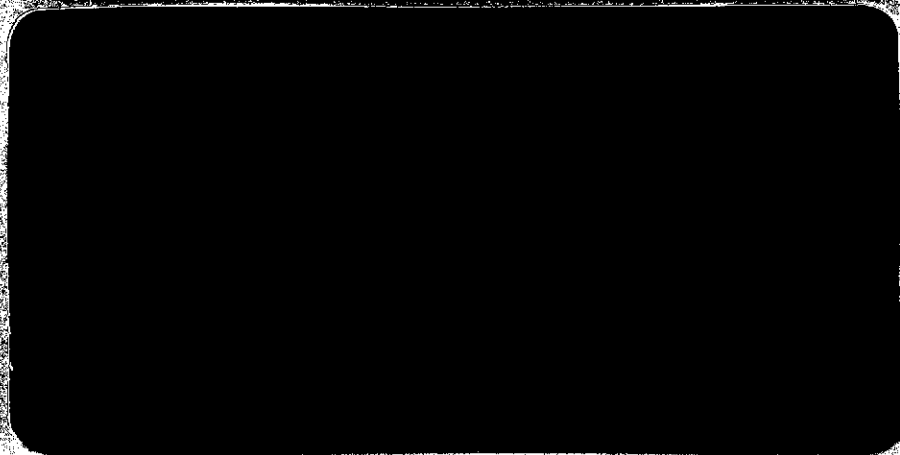
GOODYEAR AEROSPACE CORPORATION

(NASA-CR-120649) DESIGN AND FABRICATION OF
A FLEXIBLE TUNNEL FOR SORTIE LABORATORY
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GOODYEAR AEROSPACE CORPORATION

AKRON, OHIO 44315

**FINAL REPORT FOR DESIGN
AND FABRICATION OF A FLEXIBLE
TUNNEL FOR SORTIE LAB**

Contract NAS 8-30594

GER-16194

9 January 1975

**For
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812**

Foreword

This document was prepared by Goodyear Aerospace Corporation, Akron, Ohio under Contract NAS 8-30594 with George C. Marshall Space Flight Center. R. Crumbley was the primary NASA Contracting Officer Representative.

This report covers work that was started in November 1973 and completed in September 1974.

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I. Introduction and Summary

Goodyear Aerospace Corporation conducted a program to update a prototype design and fabricate a flexible tunnel in accordance with GER-15834 "Study of Large Flexible Tunnel for Shuttle/Payload Interface" dated 22 November 1972 and GAC drawing 72QS2228.

The principal elements of the contract were as follows:

- 1) Review and update the design established during NASA Contract NAS 8-28951 and reported in GER-15834.
- 2) Conduct a thermal blanket installation study.
- 3) Fabricate and deliver a 1/16th scale demonstration model of the tunnel.
- 4) Prepare a checkout test plan for the full scale tunnel.
- 5) Fabricate and deliver one full scale flexible tunnel.

Several changes resulted from the early review and updating of the design. Most of the changes were made to facilitate fabrication and had little or no effect on the functional operation of the tunnel. Below is a list of the more significant changes.

- 1) eliminated foam from bladder laminate to increase bladder flexibility;
- 2) heat treated pulley brackets, bolts, and hinge pin to 160,000 psi minimum tensile strength;
- 3) reduced meteoroid barrier from 0.5-inch to 0.375-inch.

The thermal blanket installation study resulted in developing a satisfactory method of installation by properly folding the various layers so that a uniform thickness could be maintained under the clamps. A single-lobe, full-size mockup was fabricated and cycled open and closed several times with no apparent damage to the blanket.

The 1/16th scale demonstration model of the flexible tunnel was fabricated and delivered to MSFC. The model was capable of being deployed straight or at a 90 degree angle.

A check out test plan was prepared and submitted to MSFC and subsequently approved. As a result of a shortage of funds, the testing was not performed at GAC prior to delivery.

Finally a full scale flexible tunnel was fabricated in accordance with GAC Drawing 72QS2228. There were no major problems encountered during fabrication. Following final assembly, the tunnel was inflated to minimal pressures at GAC to aid in packaging and to observe the final shaping at various increments of deployment. The tunnel acted very much as had been anticipated. The tunnel was not deployed at a 90 degree angle at GAC due to a lack of required testing fixtures.

II. Technical Discussion

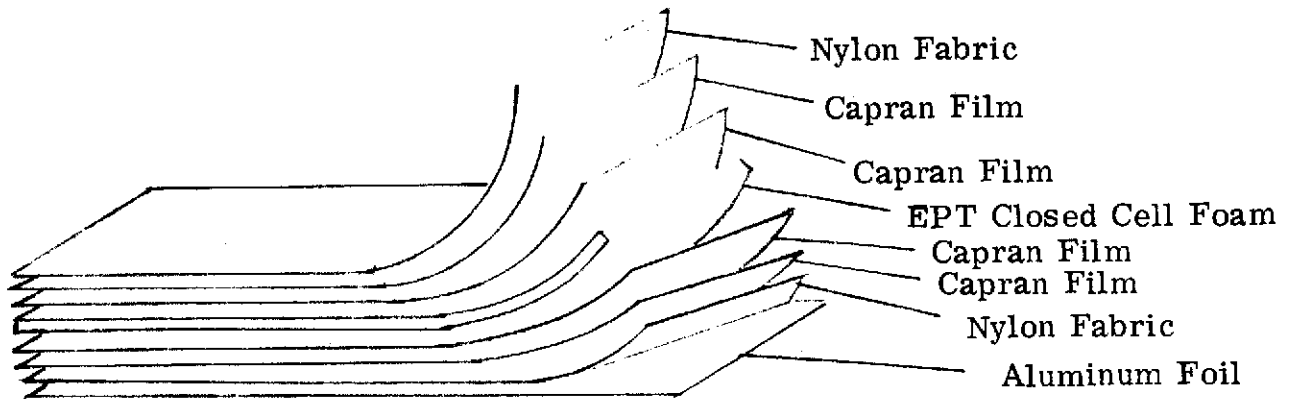
A. General

The purpose of this section of the report is to give a brief accounting of the work performed under each of the principal elements of the program.

B. Review and Update Design

A formal review and updating of the design took place during the early stages of this contract which resulted in some changes. In fact, however, this updating of design took place even through the fabrication of the full scale tunnel and is reflected in engineering orders (E. O.) written against the drawings.

1. The first significant change was to eliminate the foam from the bladder material. It was determined that there was a potential problem with the pressure bladder which could result in malfunction of the system. The potential problem related to the stiffness of the pressure bladder. The pressure bladder has low strength and must be supported by the structural layer to withstand the pressure loads. As such, the pressure bladder must be very flexible to follow the changing contour of the structural layer during deployment or retraction. It was believed that the originally proposed bladder might be too stiff to meet these requirements. Below is presented a schematic of the originally proposed laminate.



It was determined that the stiffness of this bladder could be reduced considerably by the elimination of the 0.047-inch EPT closed-cell foam. It was believed that the new more flexible bladder would better satisfy the total functional requirements of the tunnel. However, the elimination of the foam may increase the possibility of bladder puncture. To aid in reducing the sensitivity of the bladder to puncture, aluminum foil was added to both sides of the bladder. Although it was not incorporated in this tunnel design, a fabric liner could also be employed to protect the bladder from puncture.

2. A stress analysis of the pulley brackets and associated hardware resulted in changing the attachment bolt, bracket, and hinge pin from normalized to 160,000 psi minimum tensile heat-treat condition.
3. A meteoroid and thermal analysis was conducted to evaluate the following considerations.
 - a. The possibility of the thermal blanket serving a dual function as the thermal barrier and also the meteoroid barrier in an environment that will be present when the tunnel is deployed inside and or outside the orbiter bay.

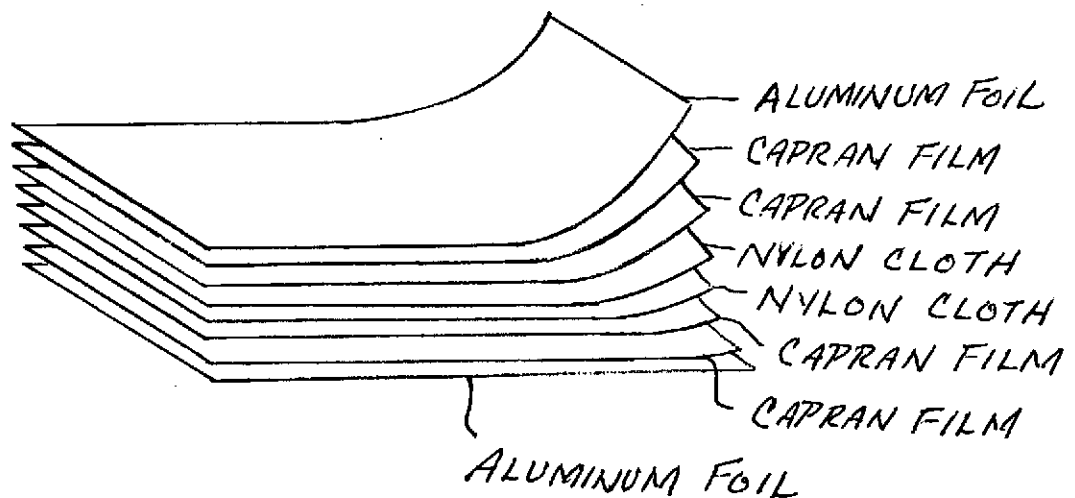
- b. Establish the maximum and minimum internal wall temperatures.
- c. Determine the total heat loss for the tunnel.

The detailed analysis is presented in the monthly status reports, GER-16160 S/4. The following is a summary of the findings from this analysis.

- a. The probability of 0.995 of no penetration can be obtained with 0.5 inch of multilayer insulation and 0.375-inch of foam regardless of the tunnel position. It was concluded that if an 0.5-inch multilayer insulation is installed, the foam meteoroid barrier is still required when the tunnel is deployed outside the orbiter bay. Since the multilayer insulation does provide some meteoroid protection, the foam thickness could be reduced to 0.375 inch thick and the tunnel would have a 0.995 probability of no puncture for a seven day mission.

If the tunnel is never deployed outside the orbiter bay, the meteoroid protection requirements are reduced since the exposed area and therefore shielding factor product is decreased to approximately 25 percent of the original value. The preliminary analysis indicated that 0.50 inch of multilayer insulation will provide 0.995 probability of no puncture for a seven day mission if the tunnel is never deployed outside the orbiter bay. However, due to uncertainties such as limited test data, variable tunnel position in the bay and variable tunnel lengths, it was recommended that the foam and multilayer insulation both be installed on the developmental tunnel. It appeared to be safe to reduce the foam thickness to 0.375 inch for any configuration.

- b. The internal wall temperature will be well within the limits of +50°F to +115°F.
 - c. The maximum heat leak will be less than 250 BTU/Hr.
4. For cost reasons, the foam meteoroid blanket was changed to charcoal color in lieu of white for the development tunnel.
 5. As a result of an error in the material specification for the bladder laminate, a reorientation of the material construction was realized. The final bladder construction is as presented below.



C. Thermal Blanket Installation Study

A single-lobe, full-size mockup for functionally testing the thermal blanket installation was built to satisfy this requirement. Since this study was only an installation study and not a thermal conductivity study, commercial grade,

aluminized one size, mylar and commercial grade fabric spacer was employed in fabricating the thermal blanket. The material was selected to simulate the physical characteristics of the thermal blanket.

After several attempts at installing the thermal blanket, a satisfactory method was devised for installation. The thermal blanket is made up of four layers with each layer consisting of twelve aluminized mylar sheets separated by fabric netting. Figure 1 is a cross-sectional view of the thermal blanket in the area of the clamps. Each layer is individually pleated and in a sequence and size such that a uniform blanket thickness is obtained under the clamp. The thermal blanket design is presented on sheet 8 of drawing 72QS2228.

The single-lobe mockup was cycled open and closed at least 12 times with no obvious damage to the blanket. Figures 2 thru 6 show the mockup fabrication sequence and also deployment sequence. Figure 2 shows the wood rings with the pleated pressure bladder installed. Figure 3 shows the thermal blanket installed over the pressure bladder. Figures 4, 5, and 6 show the fully deployed, partially deployed, and packaged thermal blanket in the deployment fixture.

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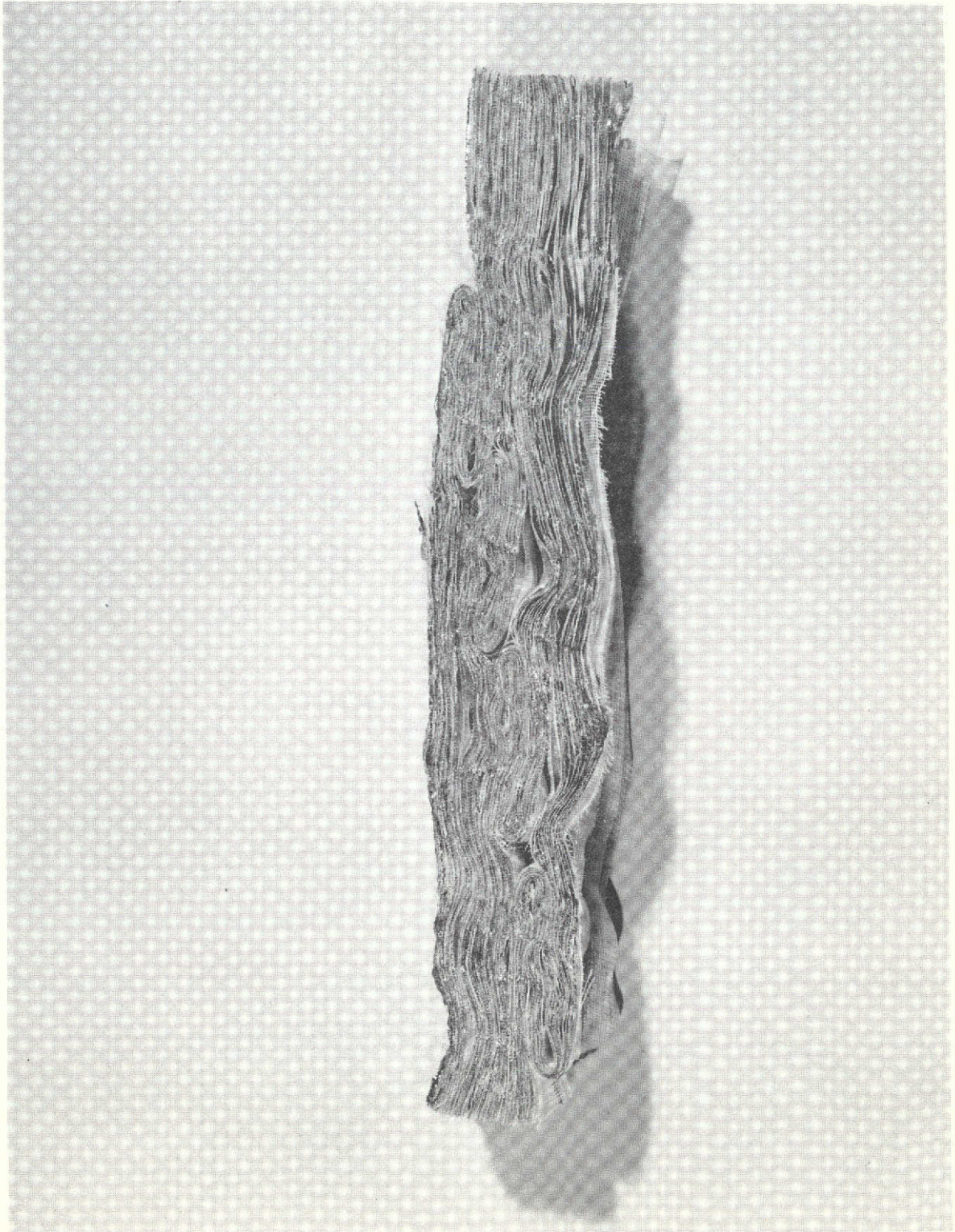


Figure 1. Cross Section Of Thermal Blanket In Clamp Area

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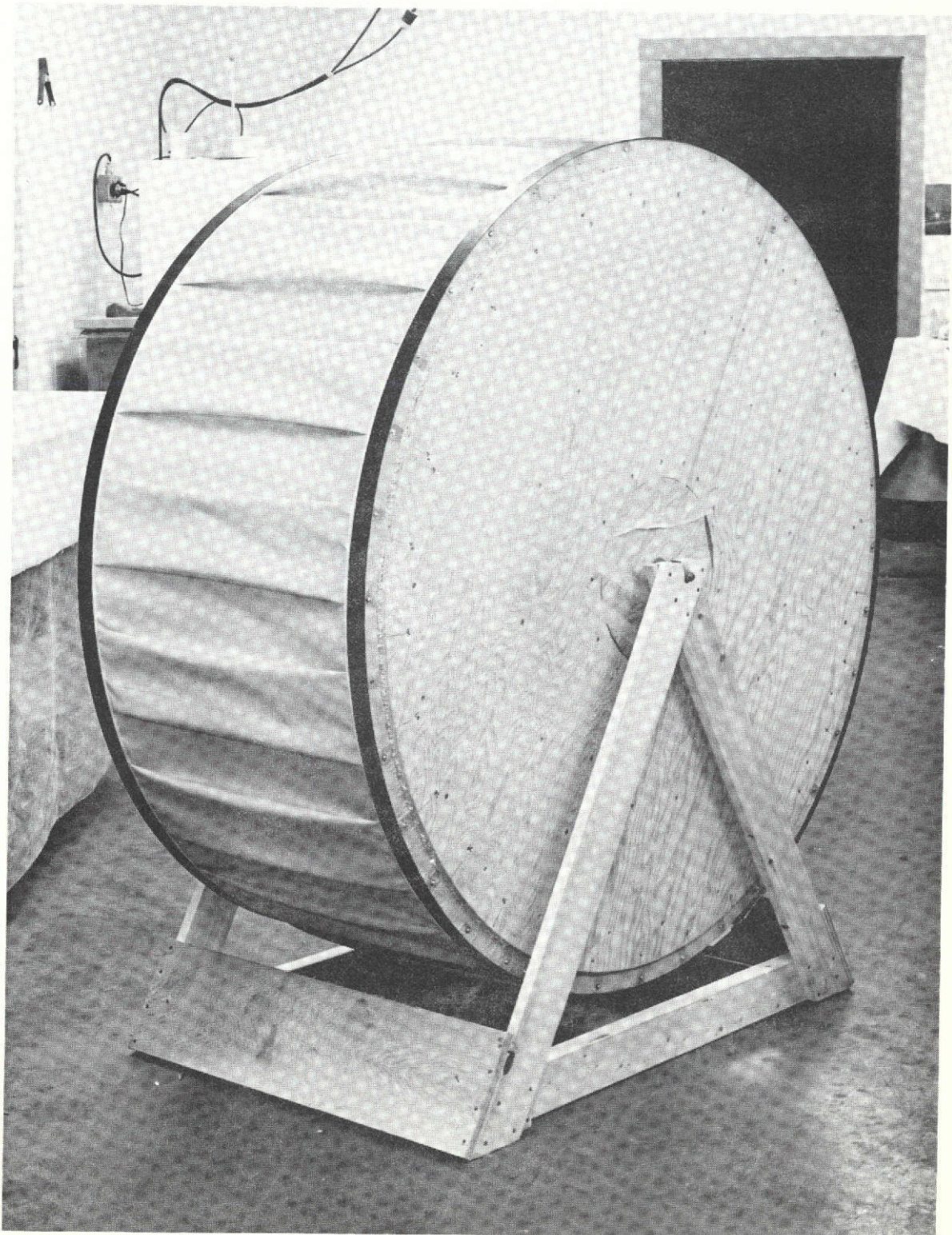


Figure 2. Pressure Bladder Installation

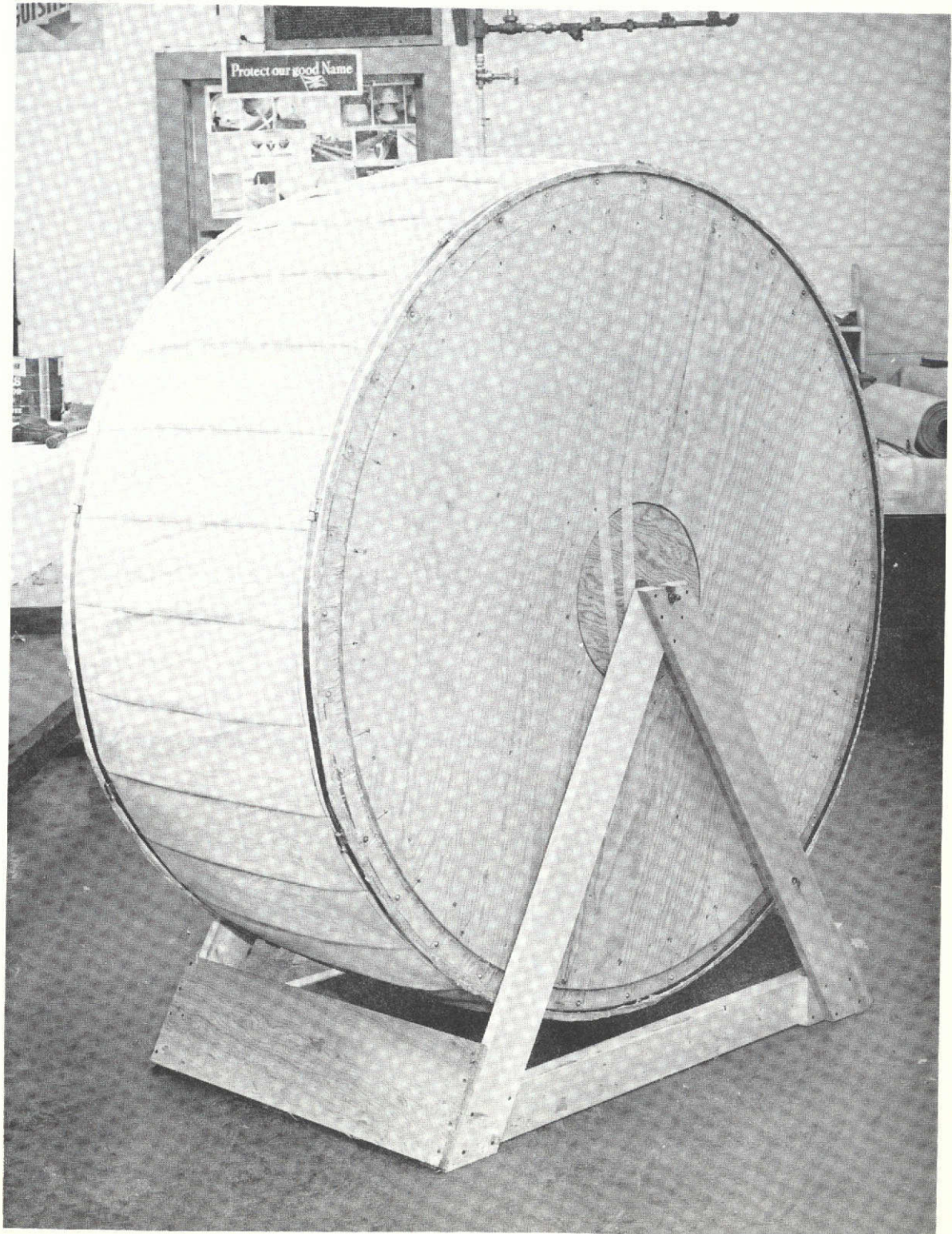


Figure 3. Thermal Blanket Installation

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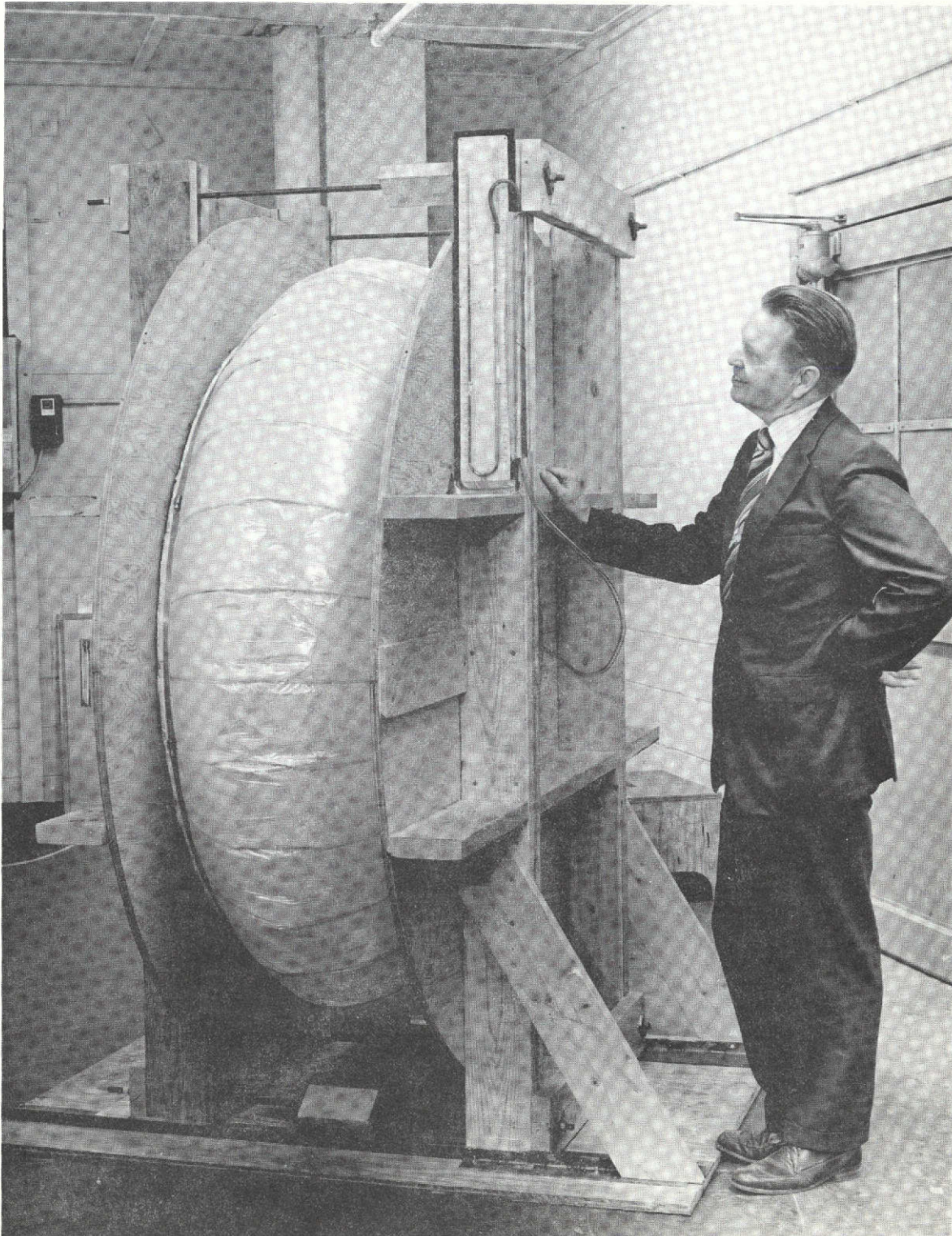


Figure 4. Fully Deployed Thermal Blanket

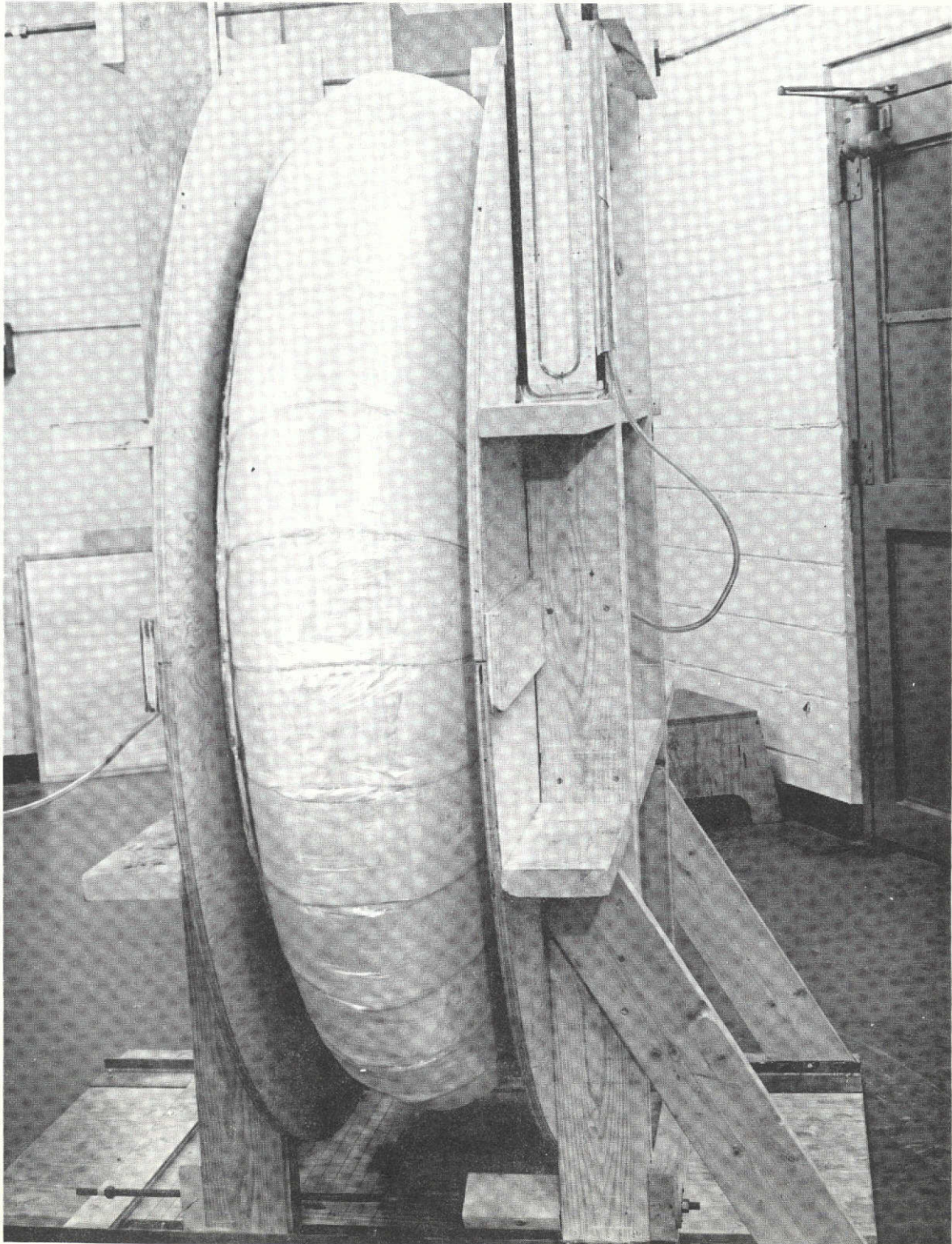


Figure 5. Partially Deployed Thermal Blanket

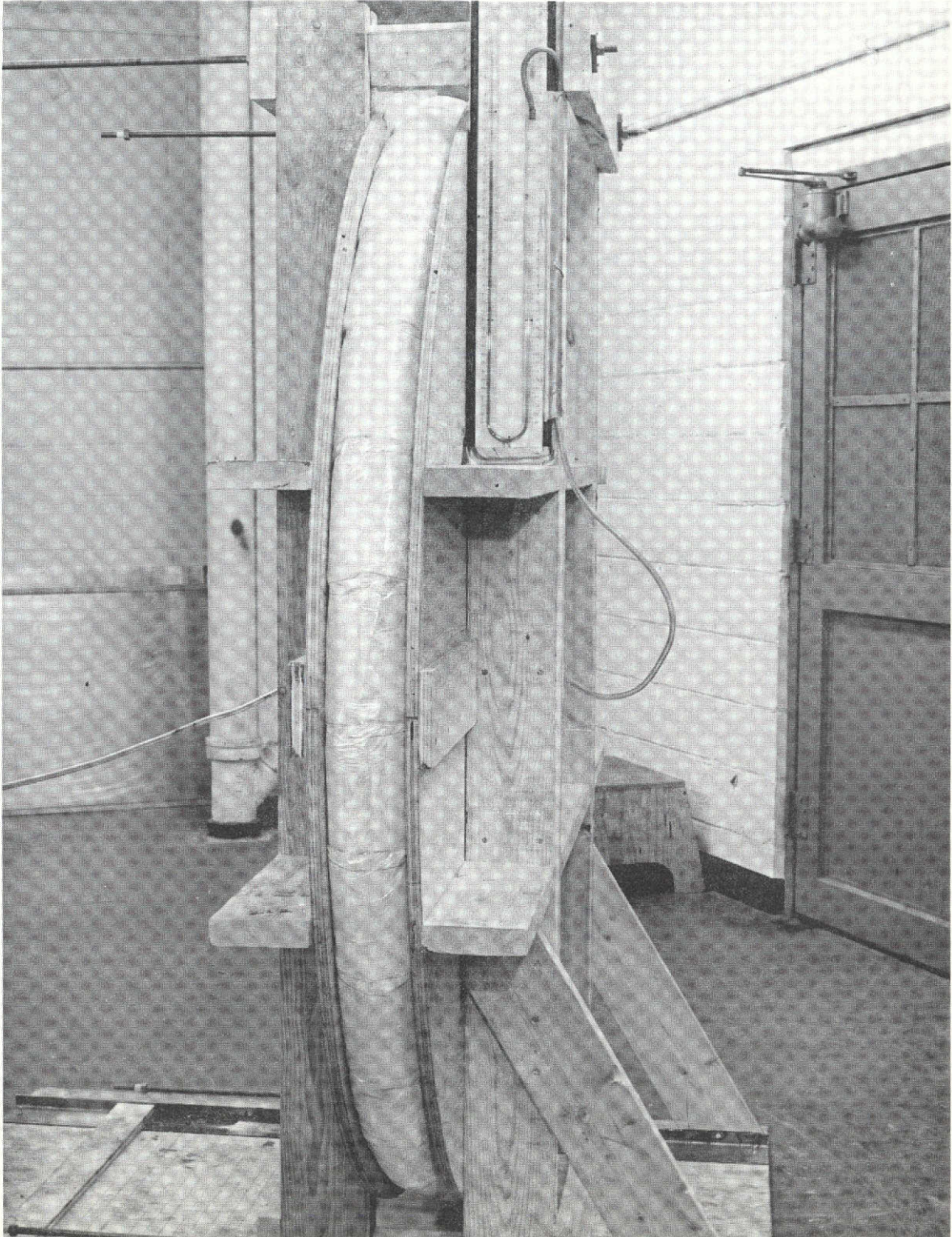


Figure 6. Packaged Thermal Blanket

D. Fabrication of Scale Demonstration Model

A 1/16th scale model of the flexible tunnel to demonstrate the functional capability of the tunnel to deploy longitudinally as well as at a 90° angle was also designed, fabricated and delivered to MSFC during the course of the contract.

Figures 7 and 8 are photographs of the model and plates showing the pulley system and cable take up reels. Figure 9 shows the cable system and structural rings installed. Figures 10, 11, 12 and 13 show the deployment sequence of the finished model for a straight deployment. Figures 14 and 15 present the deployment sequence of the model for a right-angle deployment.

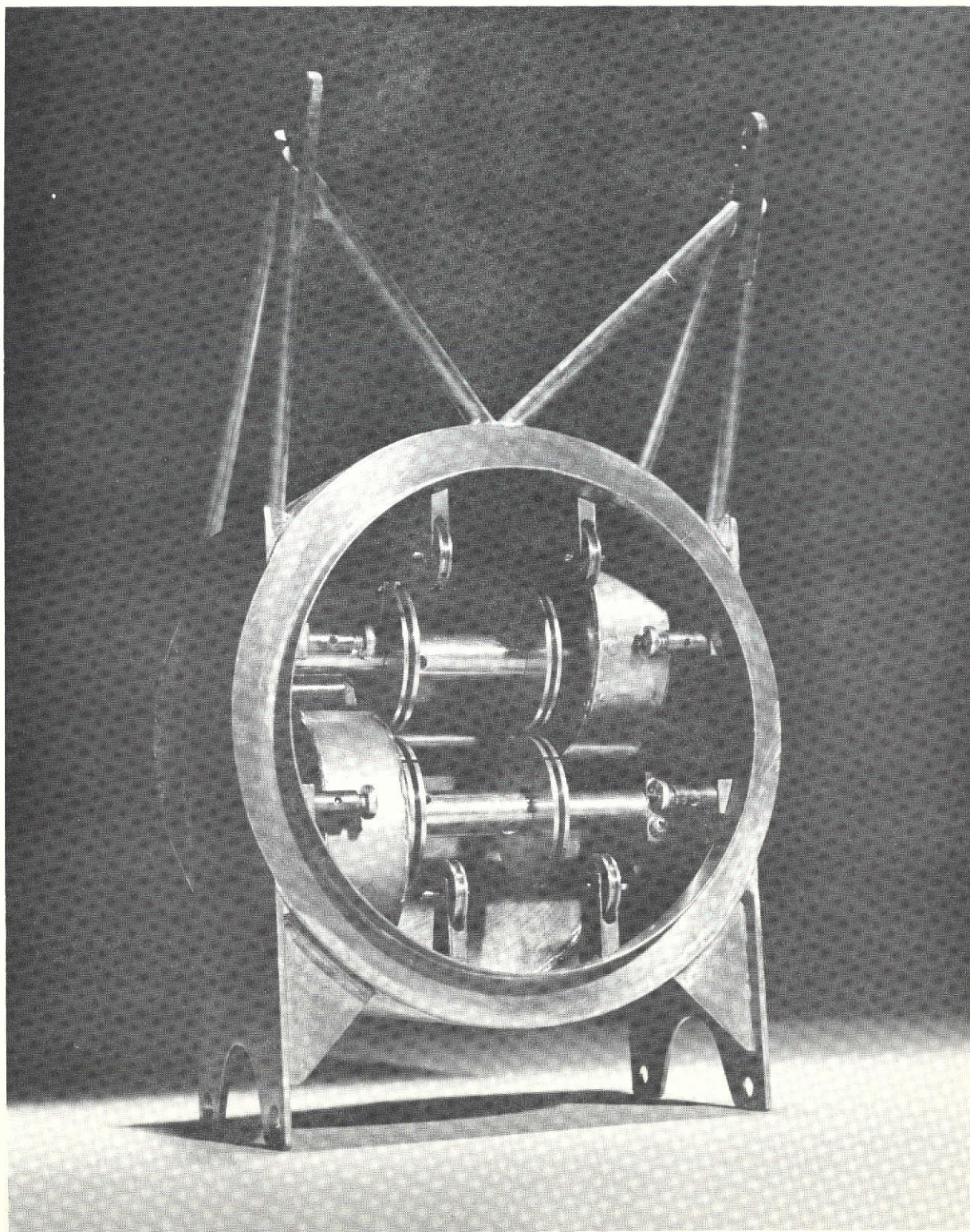


Figure 7. Scale Model End Plate

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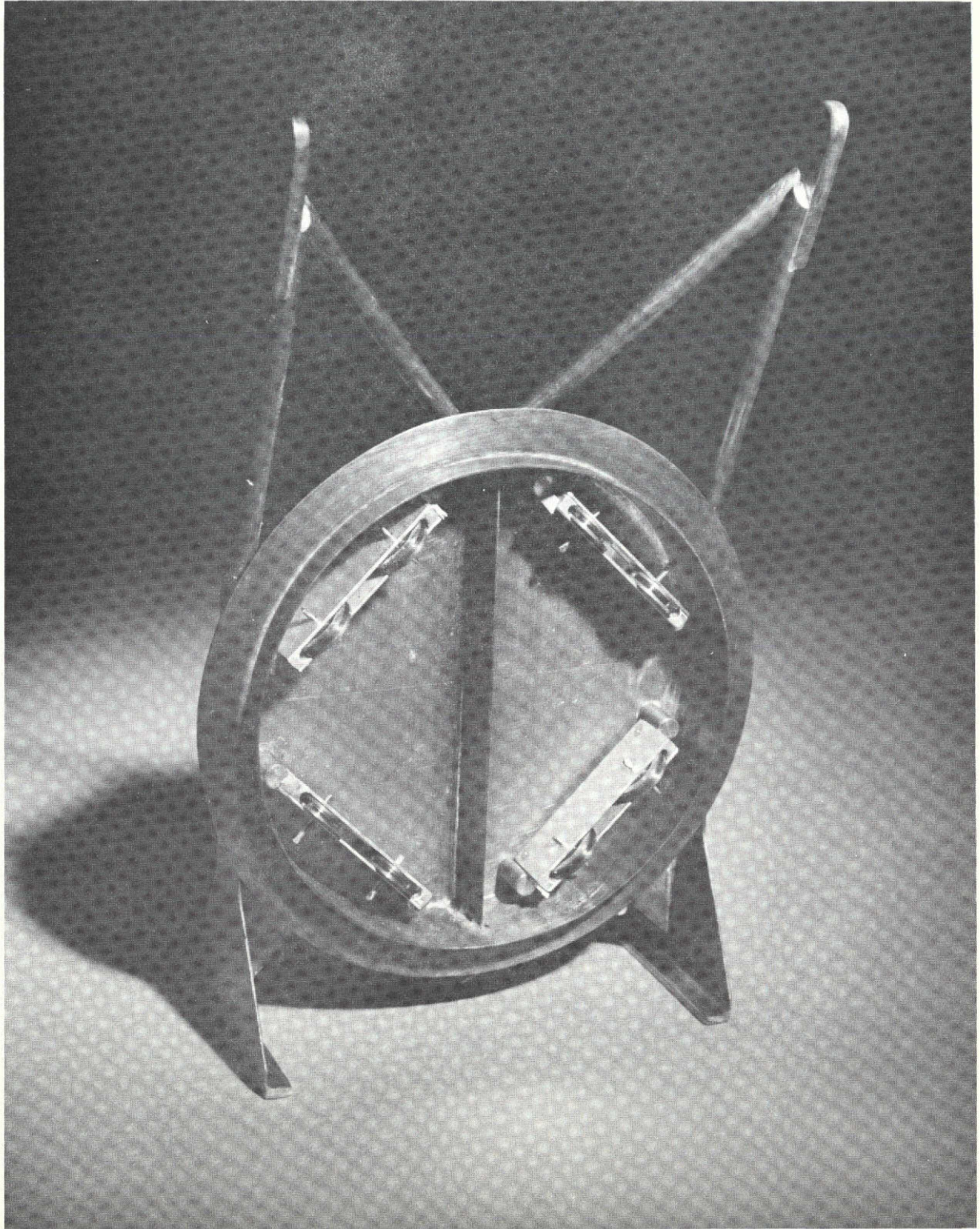


Figure 8. Scale Model End Plate

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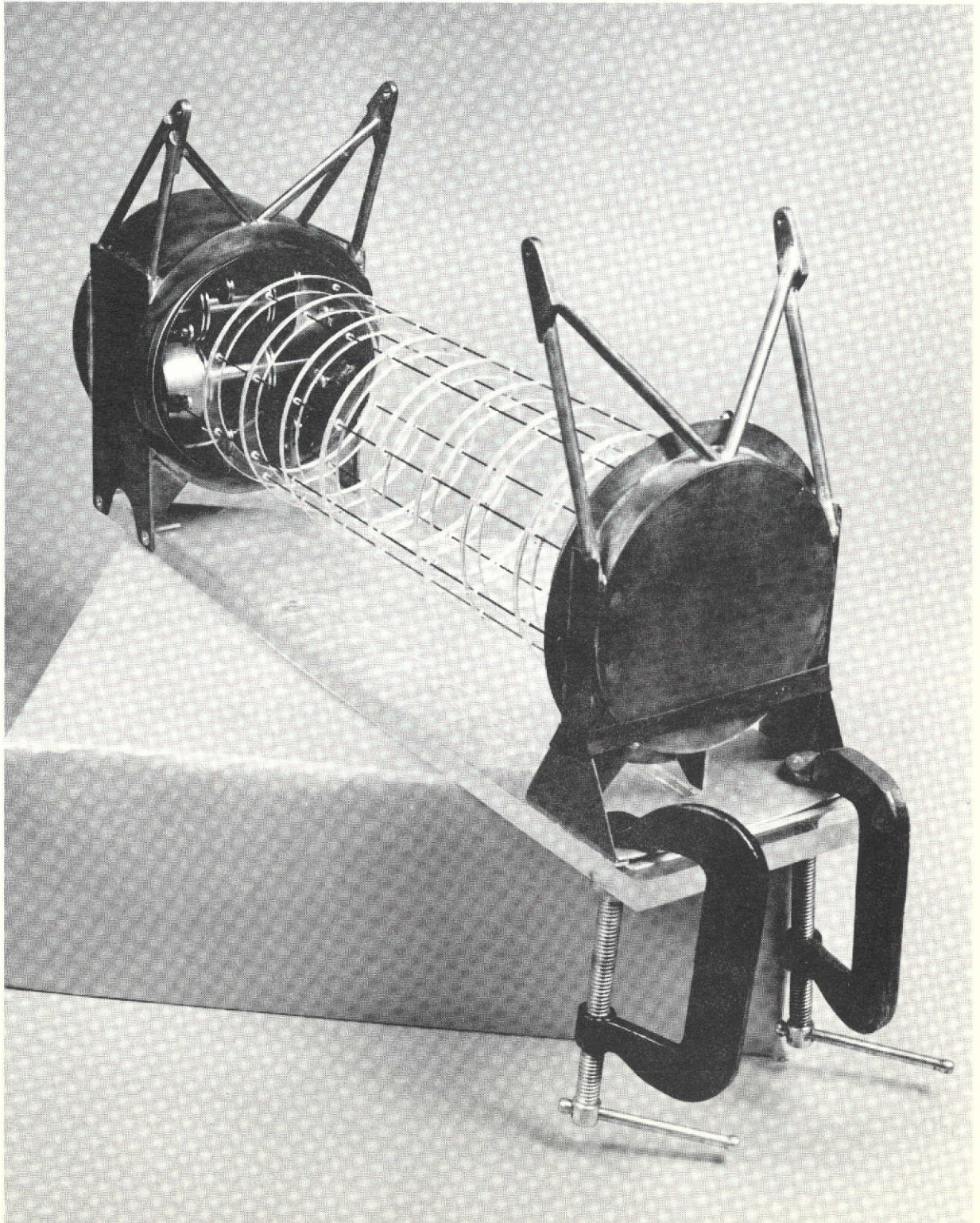


Figure 9. Cable and Structural Ring Installation on Scale Model

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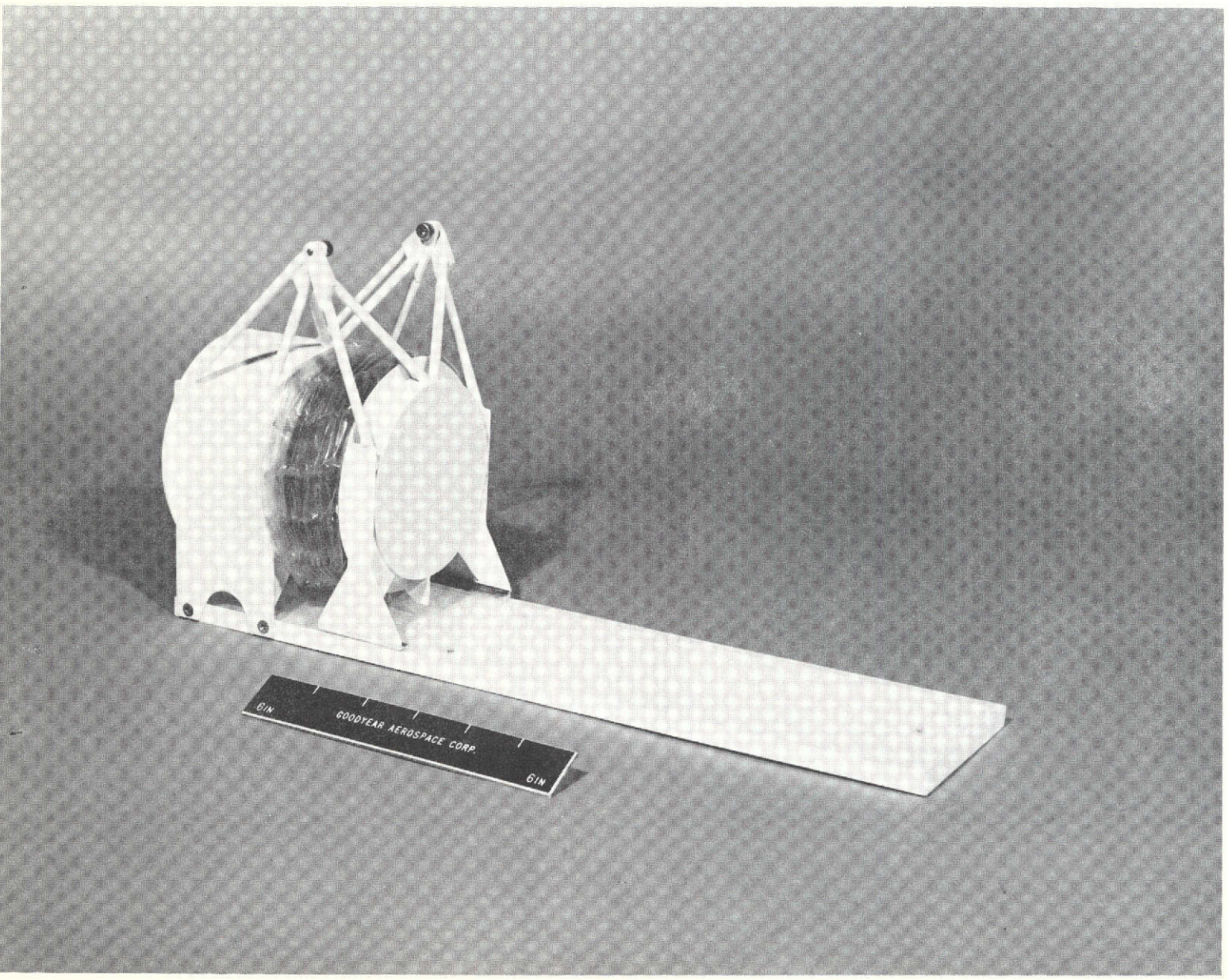


Figure 10. Scale Model In Packaged Configuration
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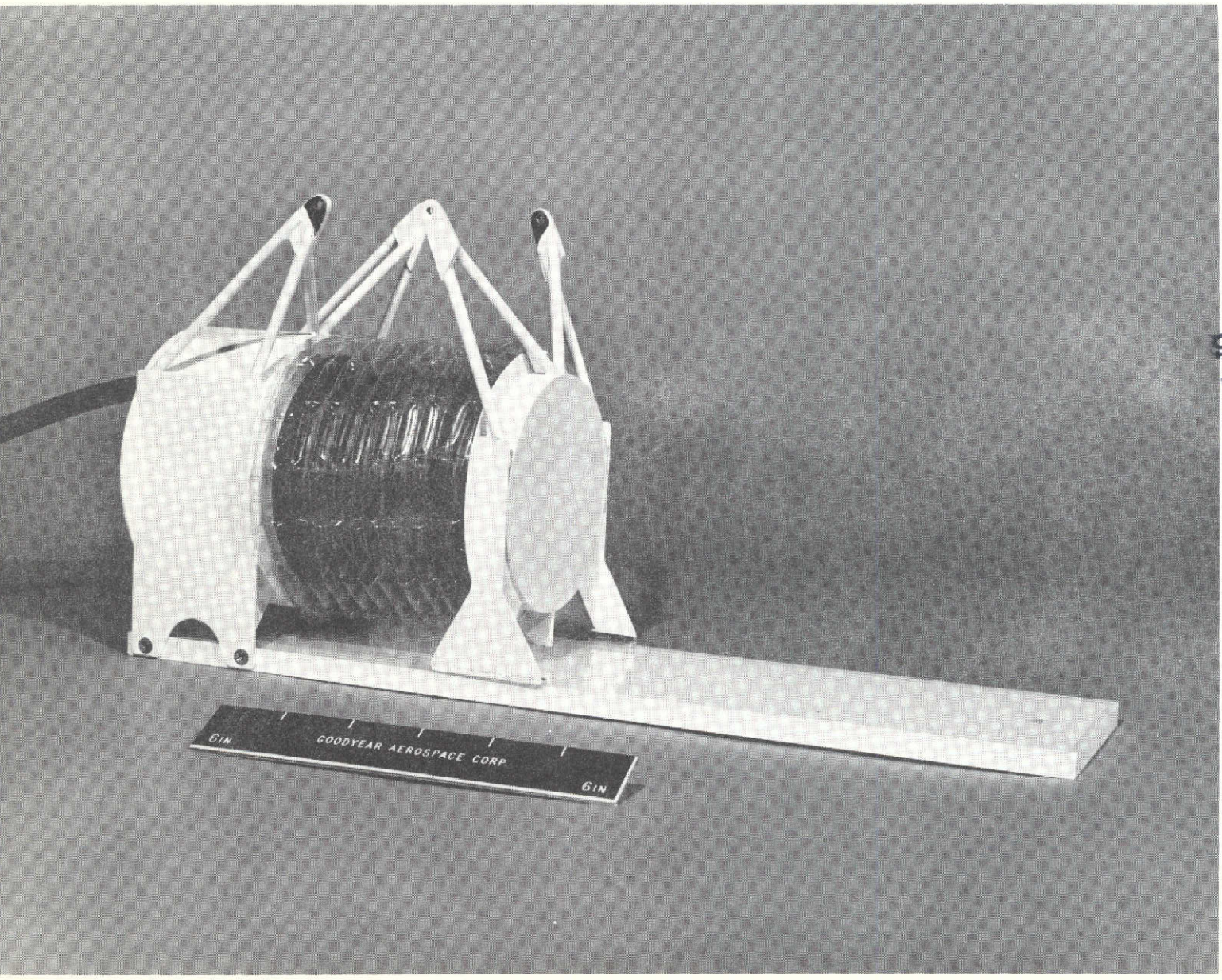


Figure 11. Scale Model About One-Third Deployed (Straight)

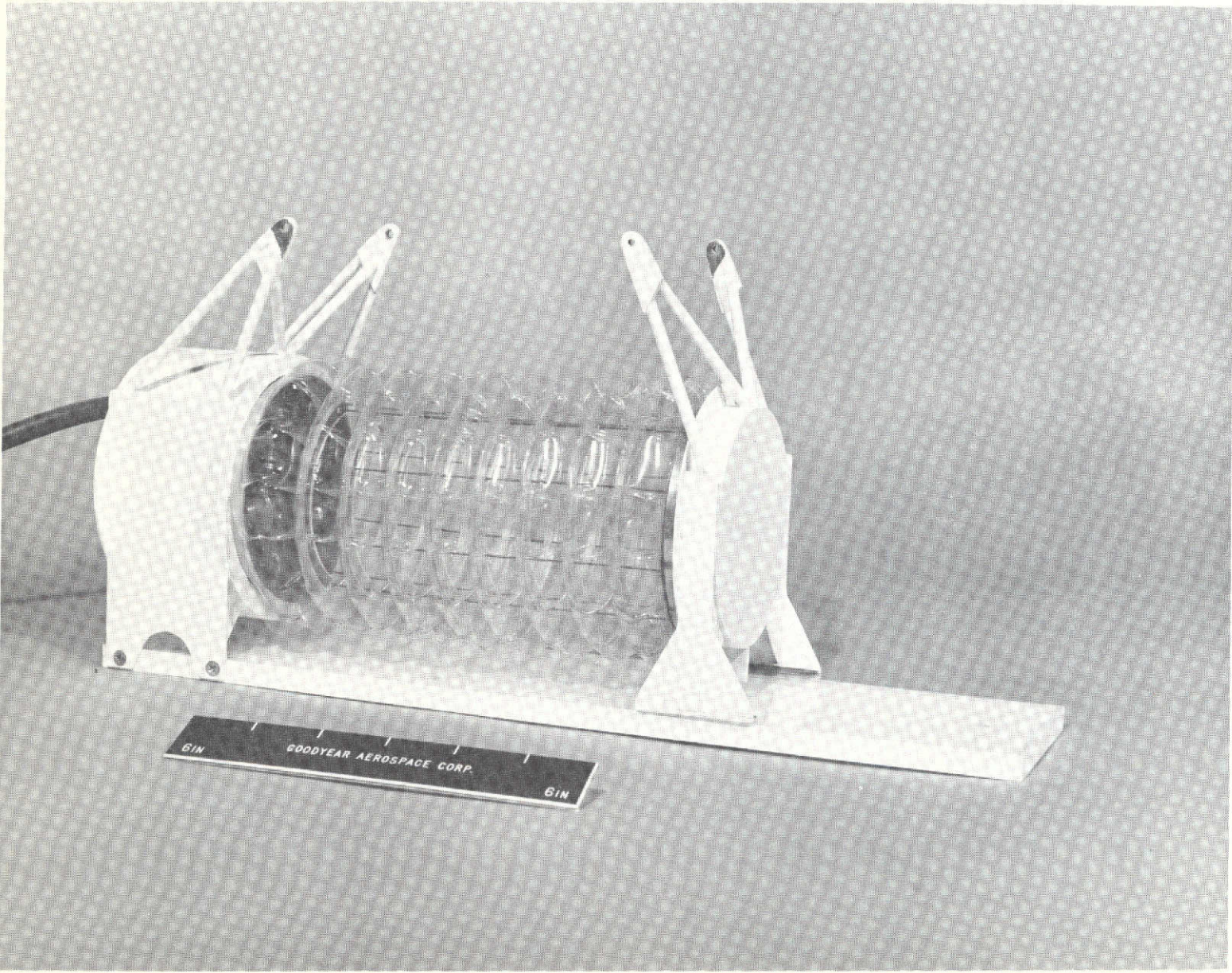


Figure 12. Scale Model About Two-Thirds Deployed (Straight)

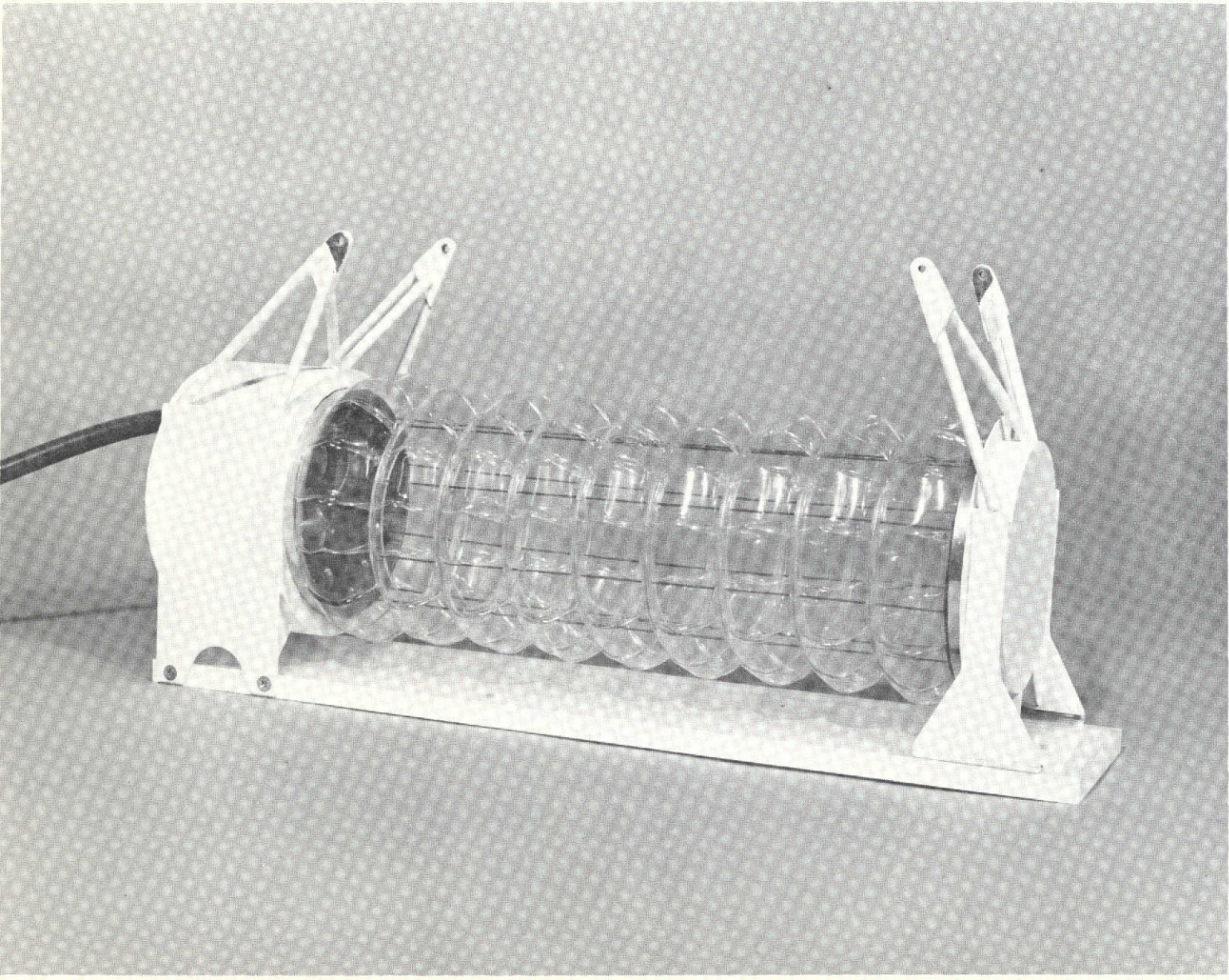


Figure 13. Scale Model Fully Deployed (Straight)

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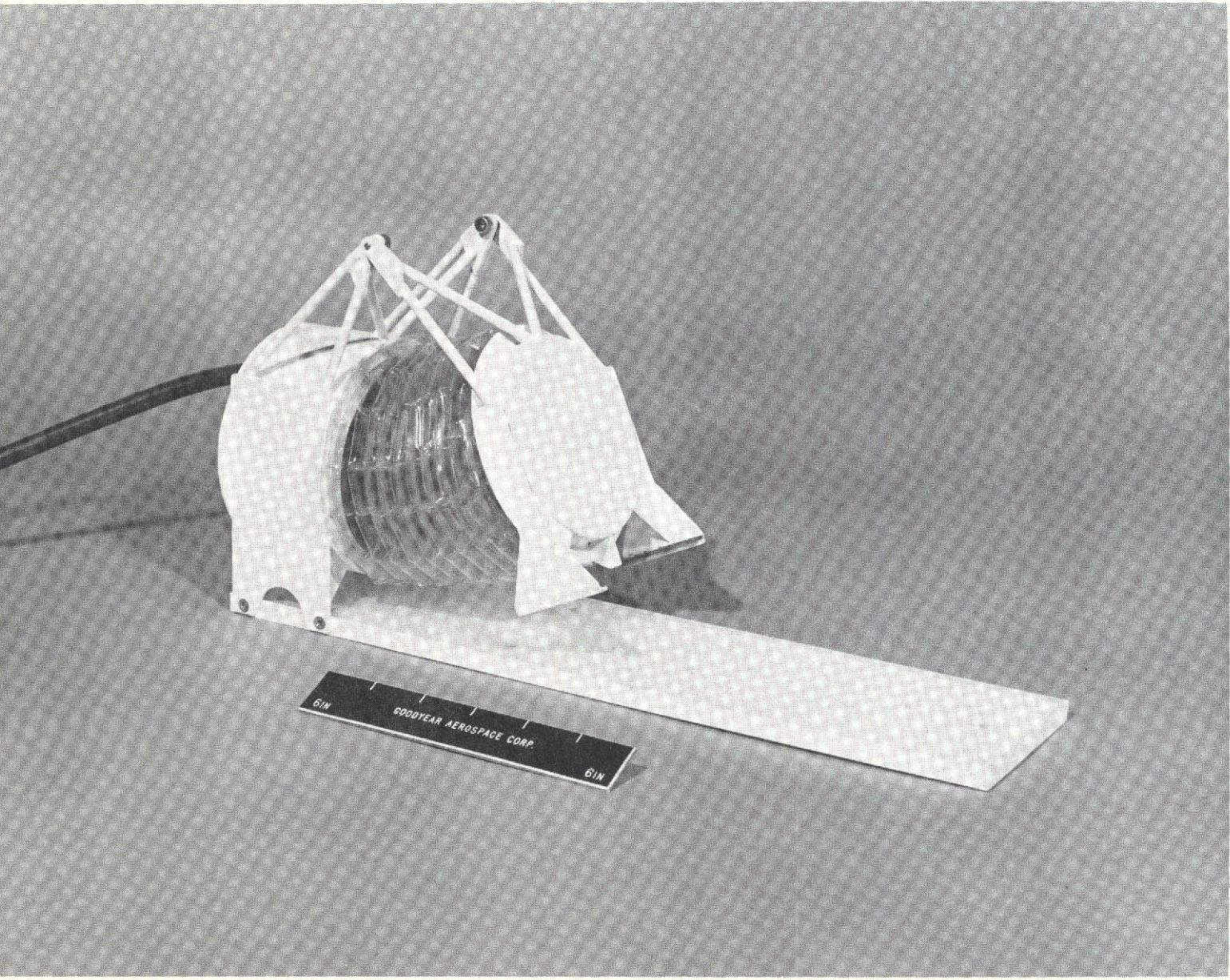


Figure 14. Scale Model Partially Deployed (90°)
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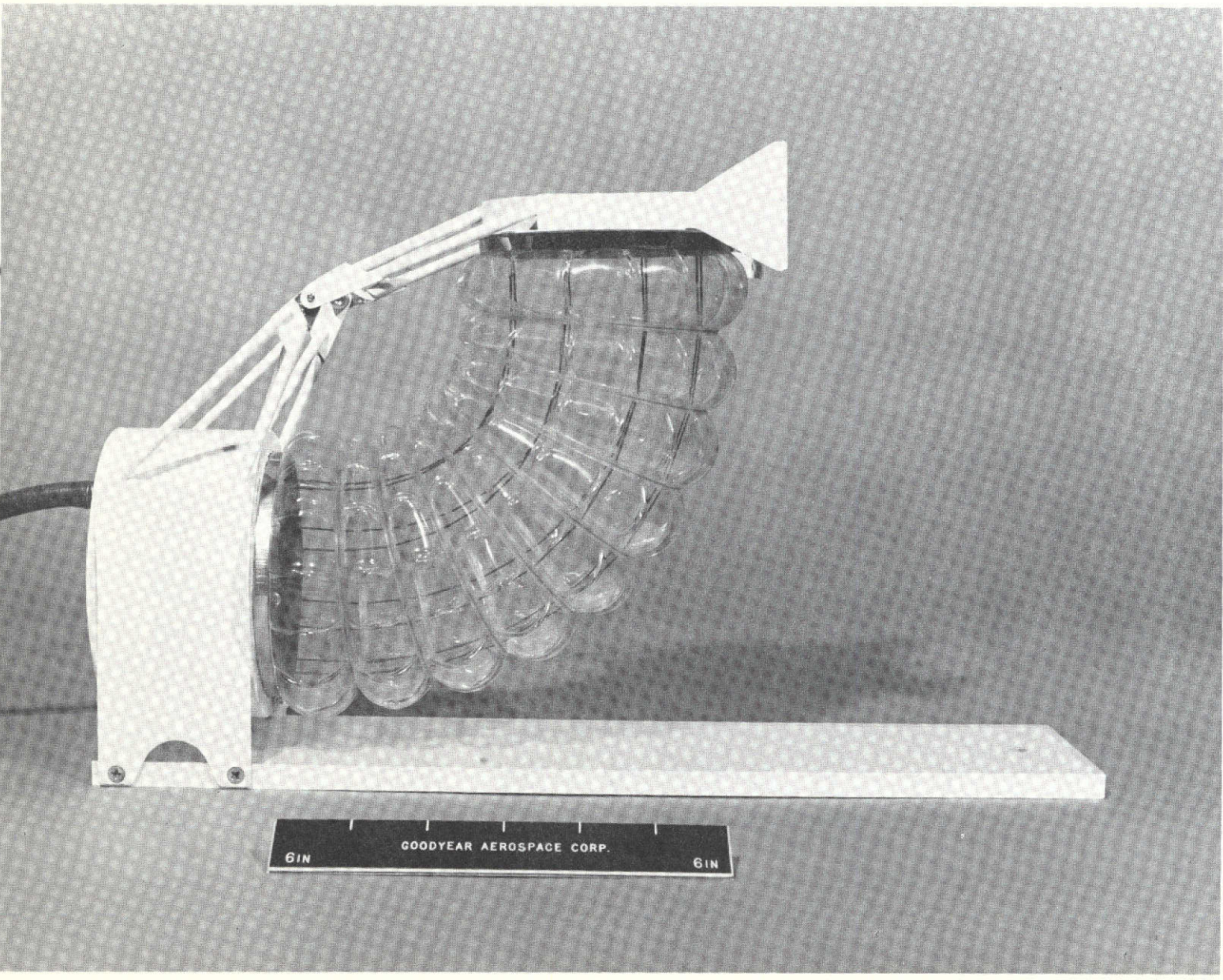


Figure 15. Scale Model Fully Deployed (90°)
23

E. Checkout Test Plan

A checkout test plan was submitted to MSFC via Goodyear Letter X58-474-8 WLS dated 11 April 1974. This plan was subsequently approved. The plan included test procedures for the following:

- 1) Proof pressure test
- 2) Leak test
- 3) Functional demonstration

As a result of a shortage of funds, the above tests were not performed at GAC prior to delivery.

F. Fabrication Of Full Size Flexible Tunnel

One complete full sized flexible tunnel was fabricated and delivered to MSFC. This section of the report summarizes the materials and fabrication sequence employed during fabrication.

1. Hardware - This section provides a brief description of materials and manufacturing techniques employed in fabrication of the major hardware items that went into the flex tunnel assembly.
 - a. -103 Ring - The -103 ring assembly was manufactured entirely of 4130 Steel. The basic ring was made by starting with 1/8 inch sheet stock and bending it to a channel shape as defined on drawing 72QS2228, sheet 3, section BB-BB. The channel was then rolled to the proper radius. The assembly consisted of 3 pieces on the inner diameter and three pieces on the outer diameter. The channels were then welded together as defined on the drawing. The twelve holes to accommodate the cables were then bored and the -3 tubes were welded in place. The -3 tubes were left extra long so that they could be faced off following normalization. A special holding fixture was manufactured for the purpose of holding the rings

during the heat treating operation so as to prevent distortion (see Figure 16). Following normalization, the -3 tubes were faced off and the assembly given a light sand blast followed by application of zinc chromate.

- b. -105 Clamp. The -105 Clamps were also manufactured from 4130 steel. Each -105 clamp contains 120° of arc. Three of the clamps bolted together were then used to retain the bladder and structural fabric down against the -103 rings. The -5 strap was machined from bar stock and then rolled to the desired radius. The -7 pads were machined and welded in place. The assembly was then attached to a special holding fixture to prevent distortion during the heat treat operation (See Figure 17). The -105 clamps were then heat treated to 150,000 psi minimum tensile. The clamps were then given a light sandblast followed by application of zinc chromate.
- c. -119 and -121 End Plate Assemblies. Both the -119 and -121 end plate assemblies were constructed entirely from 6061-T6 aluminum alloy. Both end plates were very similar with the primary differences being the pulley attachment accommodations and the -119 made allowances for the egress of the cables. The end plates were assembled in accordance with sheets 4 and 5 of GAC drawing 72QS2228. On the mating surface for the flexible portion of the tunnel, an O-ring groove was provided to aid in achieving an air tight seal. There were no special manufacturing techniques employed in the construction of these end plates.

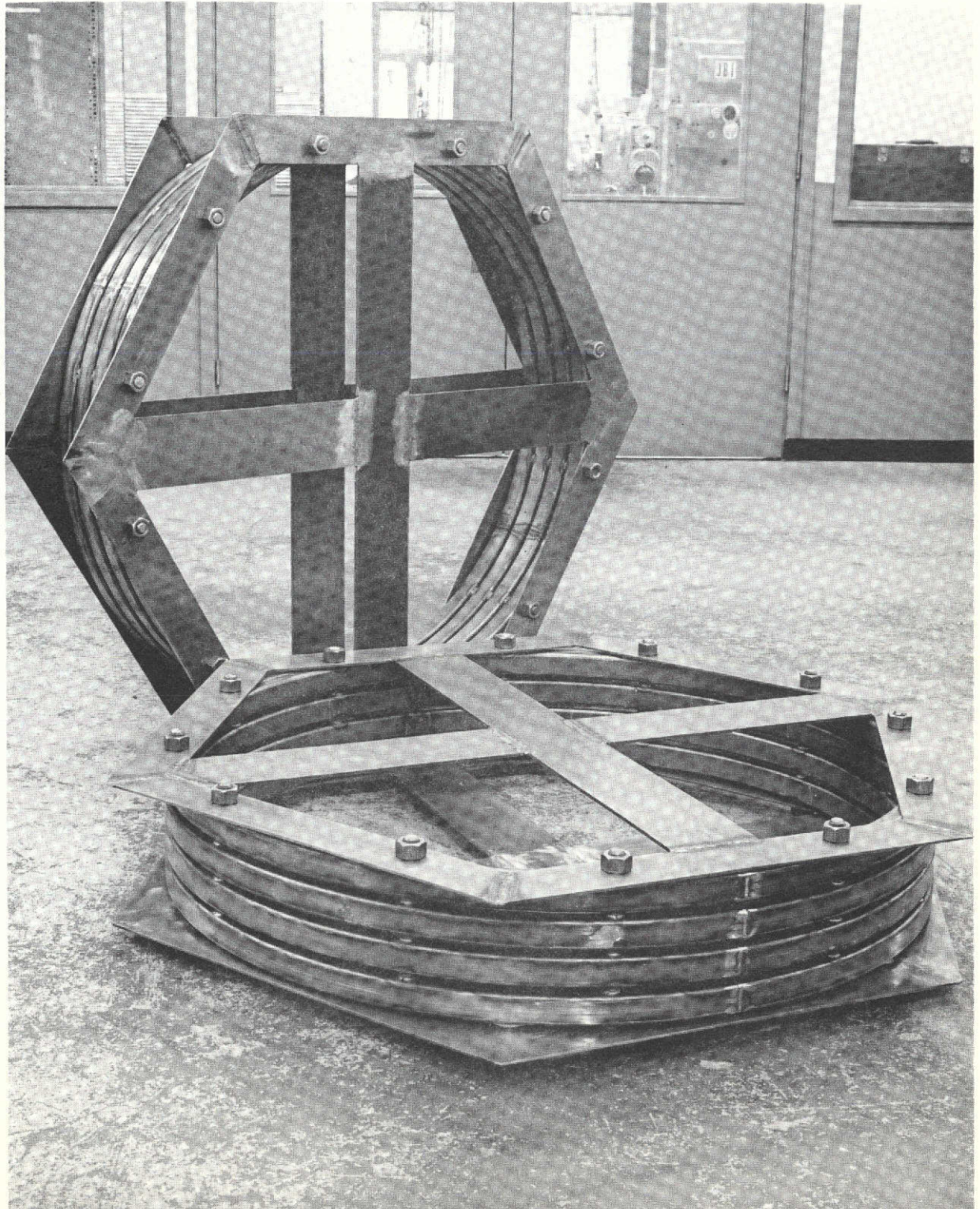


Figure 16. Holding Fixture for -103 Rings
26

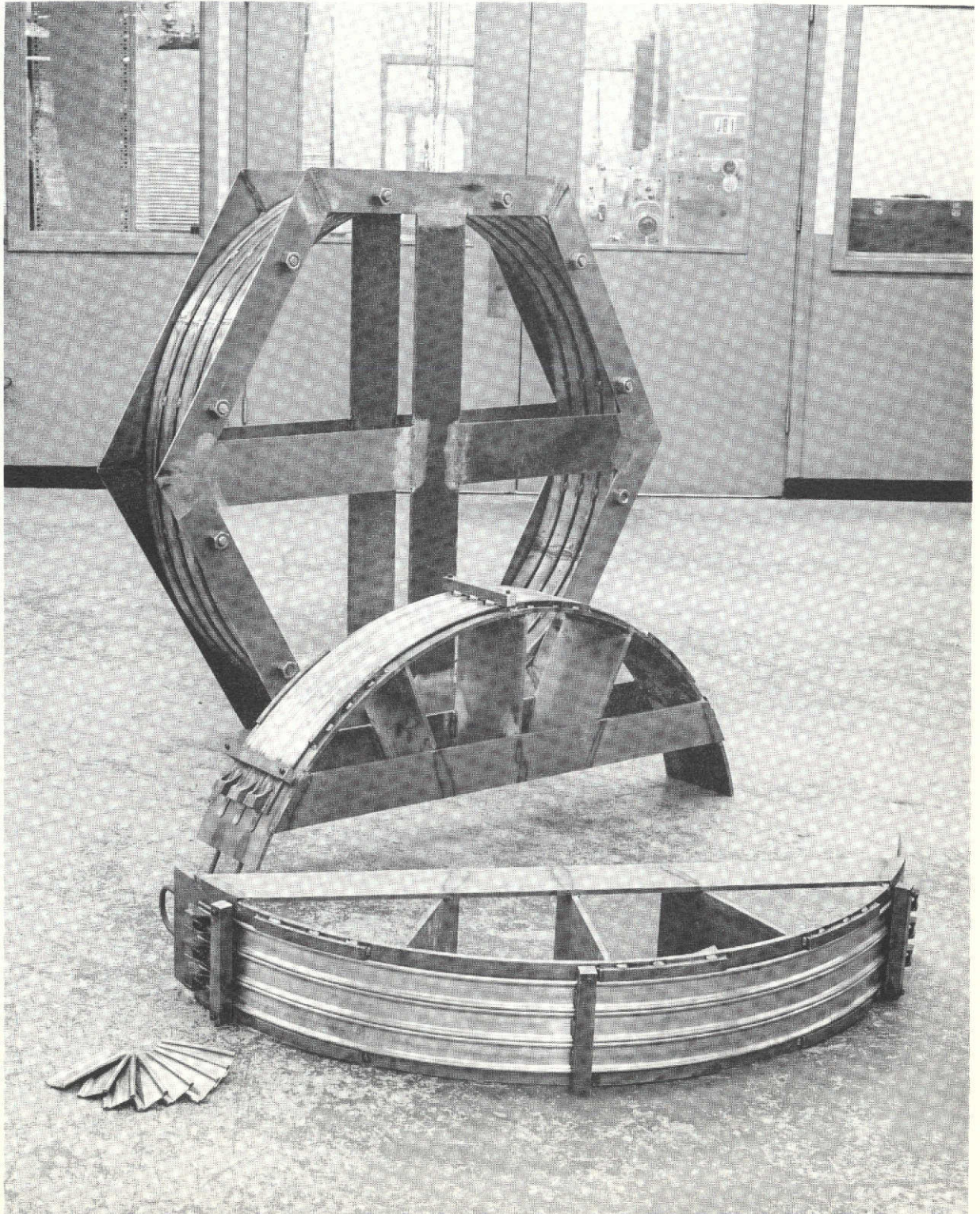


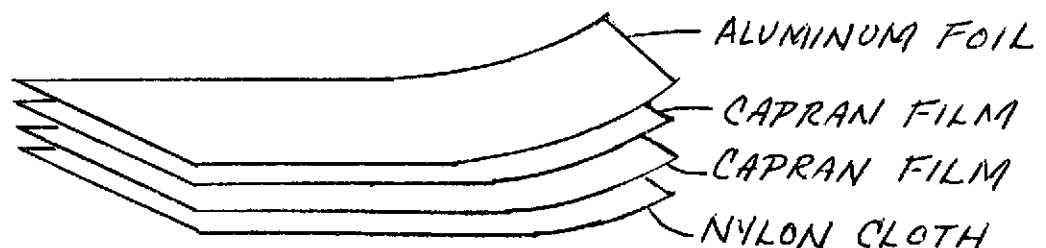
Figure 17. Holding Fixture for -105 Clamps

- d. -107 Pulley Assembly. The -107 pulley assemblies were machined from 2024T3 aluminum alloy plate per sheet 2 of drawing 72QS2228. The bearing (Model DPP10) was obtained from The Fafnir Bearing Company. The bearing was positioned in the pulley and staked in accordance with GAC Process Specification M31.
- e. -33 Fairlead. The -33 fairleads were machined from laminated phenolic per MIL-P-15035 Type FBG. The fairleads were to be used as guides for the cables through the -103 rings. The fairleads were split to provide for ease of replacement, if required. Once in position, the fairleads were held in place with snap rings.

2. Software

This section contains a brief description of the materials and fabrication techniques employed in the manufacture of the software items that went into the flex tunnel assembly.

- a. -123 Bladder. The bladder is constructed from a film cloth laminate consisting of nylon cloth, capran film and aluminum foil all joined with a polyester adhesive. The material was laminated in accordance with Goodyear's Material Specification, 74QS431. The construction is presented below.



The bladder consisted of two plies of the above material with the aluminum foil being on both outer surfaces. The material was plied up into a cylinder with longitudinal seams. The seams between the inner and outer plies were staggered so as to prevent a buildup in thickness and precluded the possibility of a direct leak path. Once in the form of a cylinder, the folds were made in accordance with sheet 6 of Drawing 72QS2228 section T-T. Filler pieces were then bonded in place per that same section except that all filler pieces were attached to the outer surface. The purpose of these filler pieces was to provide for a uniform thickness under the clamps. Two folds and filler pieces were left out until final assembly to allow for adjustment.

- b. -125 Structural Cylinder. The -125 structural cylinder was manufactured from woven Kevlar cloth having a basic strength of 1500 x 1500 lb/in (plain weave). As with the bladder, the cloth was sewn into a cylinder and the folds and filler strips were sewn in place. Two folds and filler strips were again omitted until final assembly to allow for adjustment. The -31 aluminum spacer was sewn into the ends as defined in Detail V, Sheet 6 of Drawing 72QS2228.
- c. -127 Thermal and Meteoroid Blanket. The -127 Meteoroid Blanket was constructed of 0.375 inch thick polyurethane foam. The blanket was constructed with longitudinal butt splices with nylon tape reinforcements. Nylon tape reinforcements were also bonded in the clamp areas and the folds were bonded in place. The folds were then sewn to aid in maintaining the shape until clamped. Two folds were omitted to allow for adjustment at final assembly. Also, the

blanket was left as a large rectangular piece with the intention of making final splice at final assembly.

3. Final Assembly. This section describes the sequence of events and the techniques employed in the final assembly of the Flexible Tunnel. Final assembly began by suspending the -103 rings with internal support. They were spaced at the desired distances and the distances were maintained using pipes with lockable positioning rings. (This can be observed in Figure 18.) The -123 bladder was then slipped over the rings and positioned (see Figure 18). The final folds were then made and the filler strips attached (see Figure 19). The -125 structural cylinder was then positioned over the bladder and the final folds and filler strips were hand sewn in place. The -31 spacers were then bonded into the ends of the bladder. The -105 clamps were installed over each -103 ring, sandwiching the bladder and structural cylinder. The -119 and -121 end plates were installed with an O-ring between the bladder and end plates and with a potting compound semi-soft between the faying surfaces to prevent leakage. The cables and pulley system was then installed as defined on the drawing (see Figure 20). The ends of the cables were left extra long to allow for flexibility in testing at MSFC. The meteoroid blanket (3/8" foam) was wrapped around the tunnel and the final folds and closure seams were made (see Figure 21). A protective blanket of nylon cloth was then applied over the foam. Hose clamps were positioned over the foam and nylon at each -105 clamp and tightened down so as to maintain the foam and nylon in their proper position. This essentially completed the assembly of the flexible tunnel.

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Figure 18. -123 Bladder Positioned Over -103 Rings

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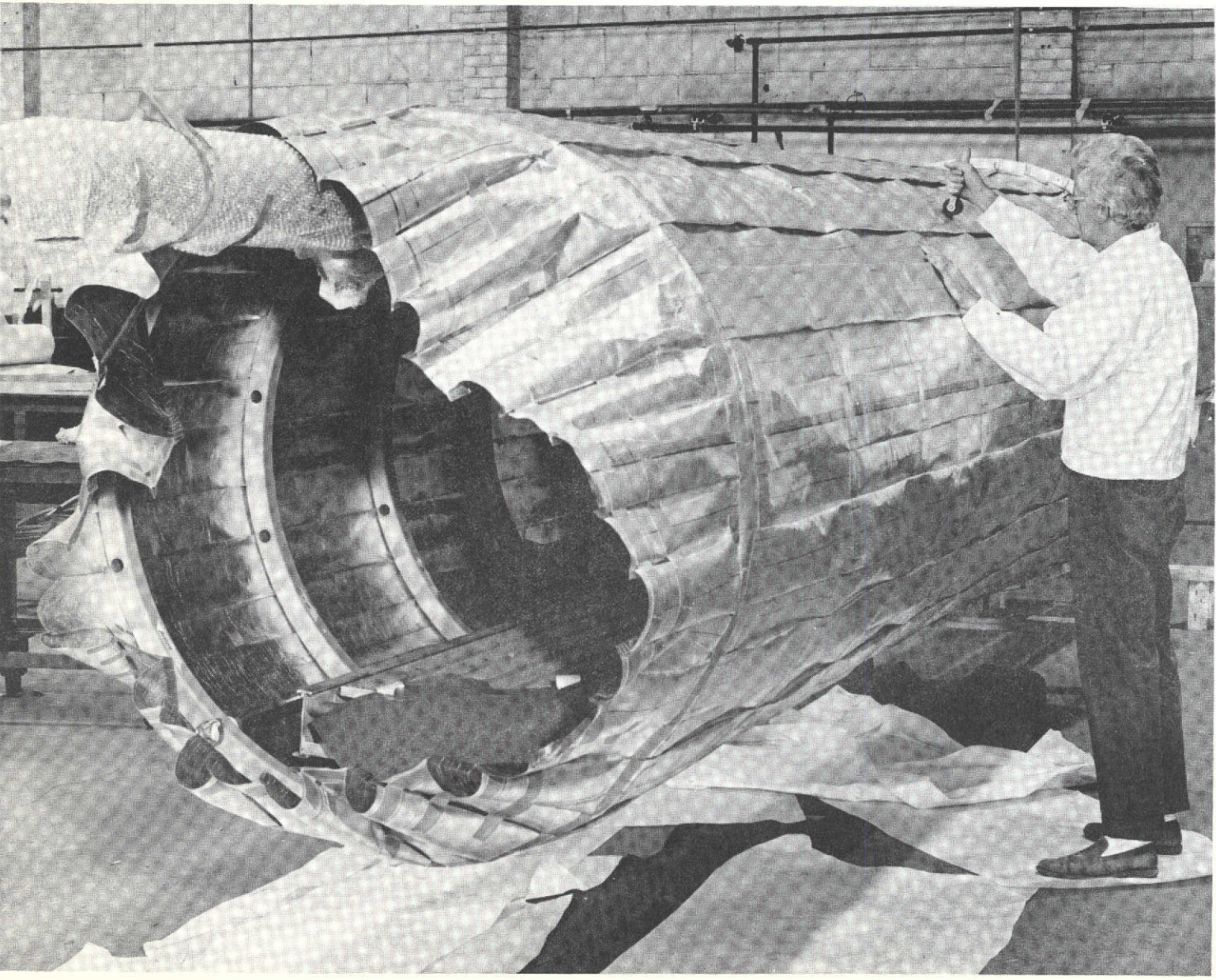


Figure 19. Final Folding of -123 Bladder
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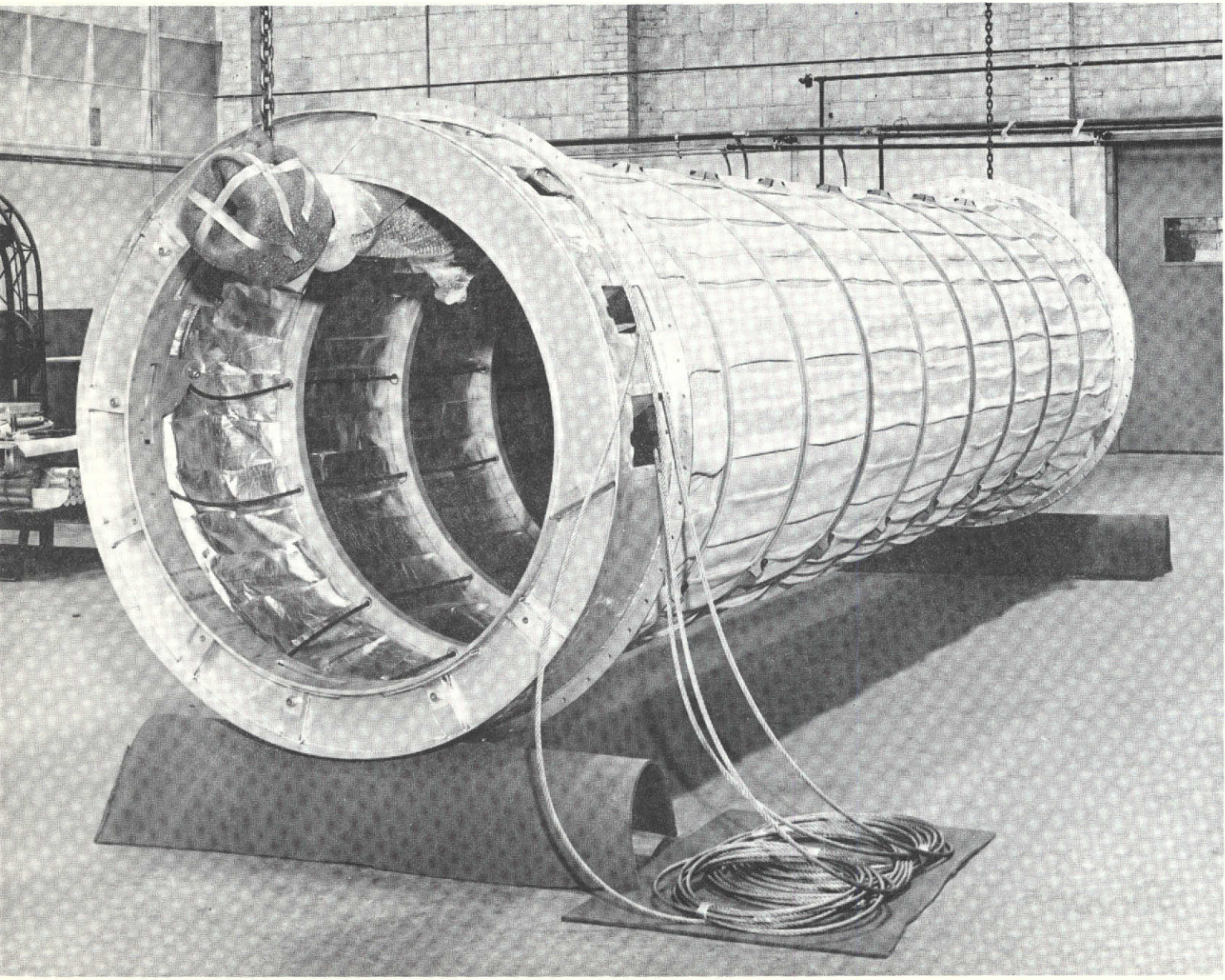


Figure 20. Tunnel with Structural Cylinder, Clamps and Cables Installed

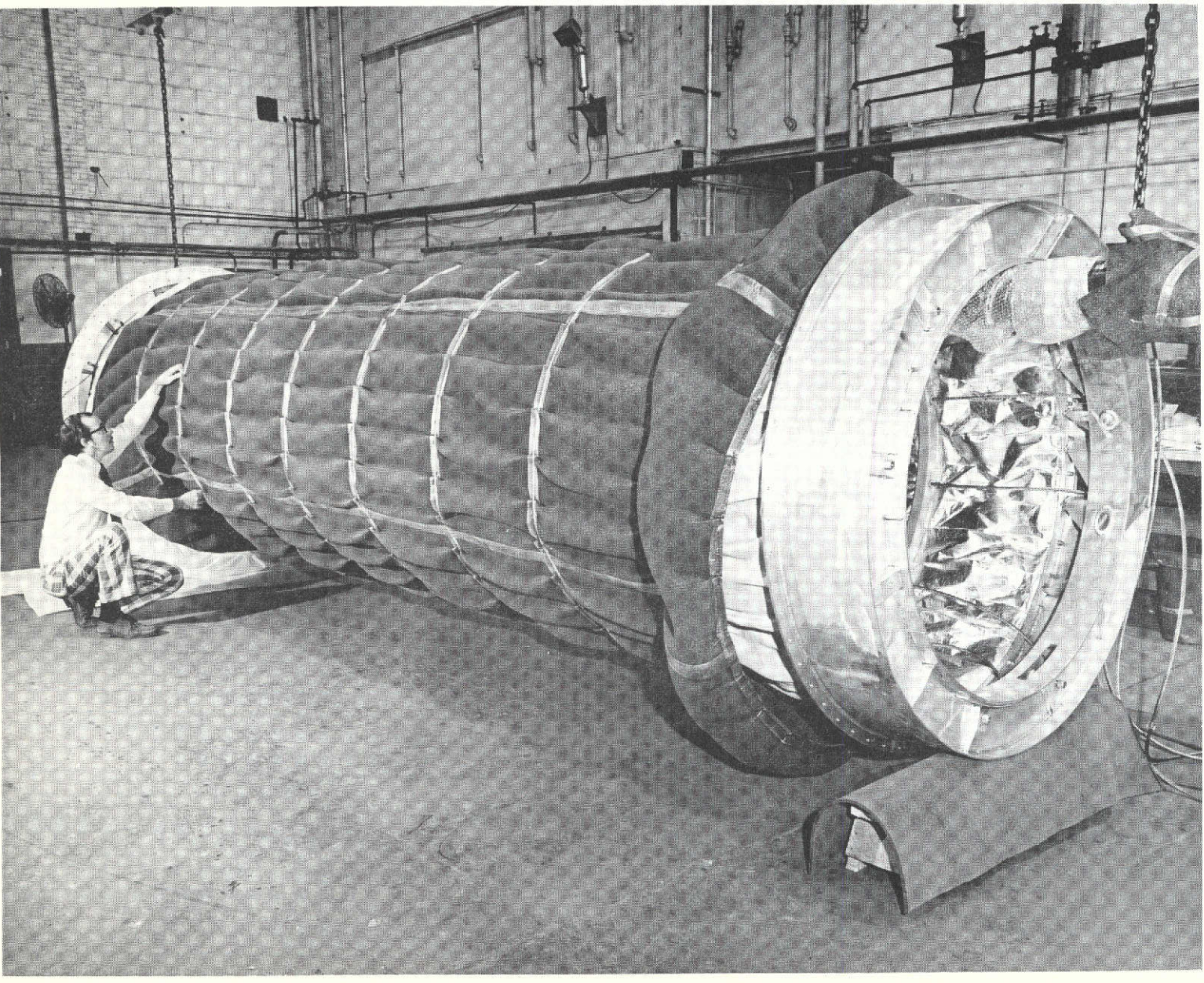


Figure 21. Installation of Meteoroid Blanket

In order to package the tunnel for shipment, it was necessary to inflate the assembly to properly achieve the lobed effect which in turn allowed for a mannerly reduction in tunnel length without the risk of improper or detrimental creases occurring in the bladder material. Consequently, the tunnel was suspended with a series of slings around each ring and end plates (see Figure 22). Fabric end closures were fabricated and attached to the end plates to allow for pressurizing the tunnels to minimal pressures. While inflated, a series of photographs were taken for record purposes. The photographs are presented in Figures 23, 24 and 25 with Figure 23 being essentially fully extended and Figures 24 and 25 being intermediated positions. It was demonstrated that the tunnel could collapse to a length of 20.5 inches between the end plates. Figures 26 and 27 are internal and external photographs of the tunnel completely collapsed. This is the mode in which the tunnel was shipped to MSFC.

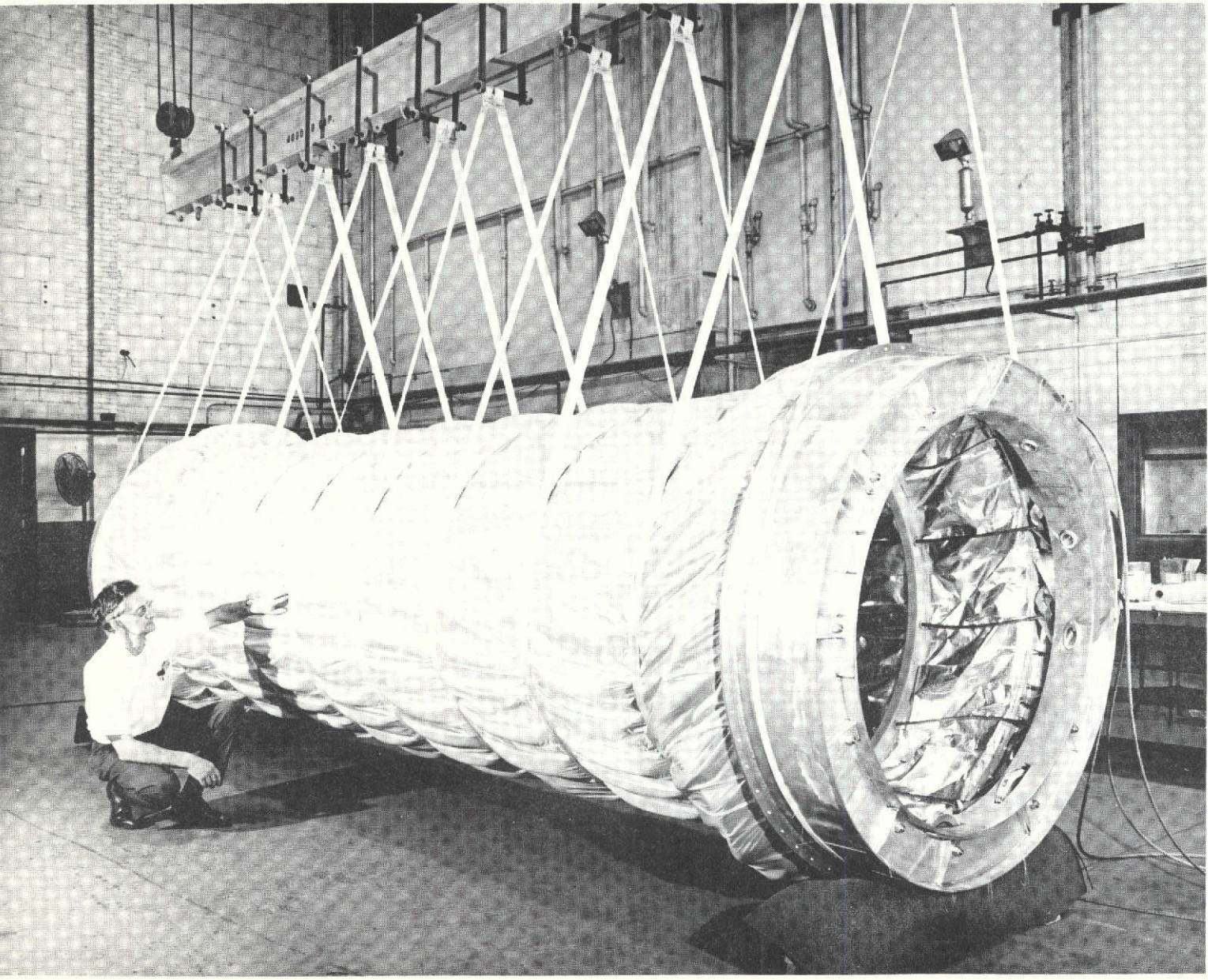


Figure 22. Tunnel Suspended with Slings

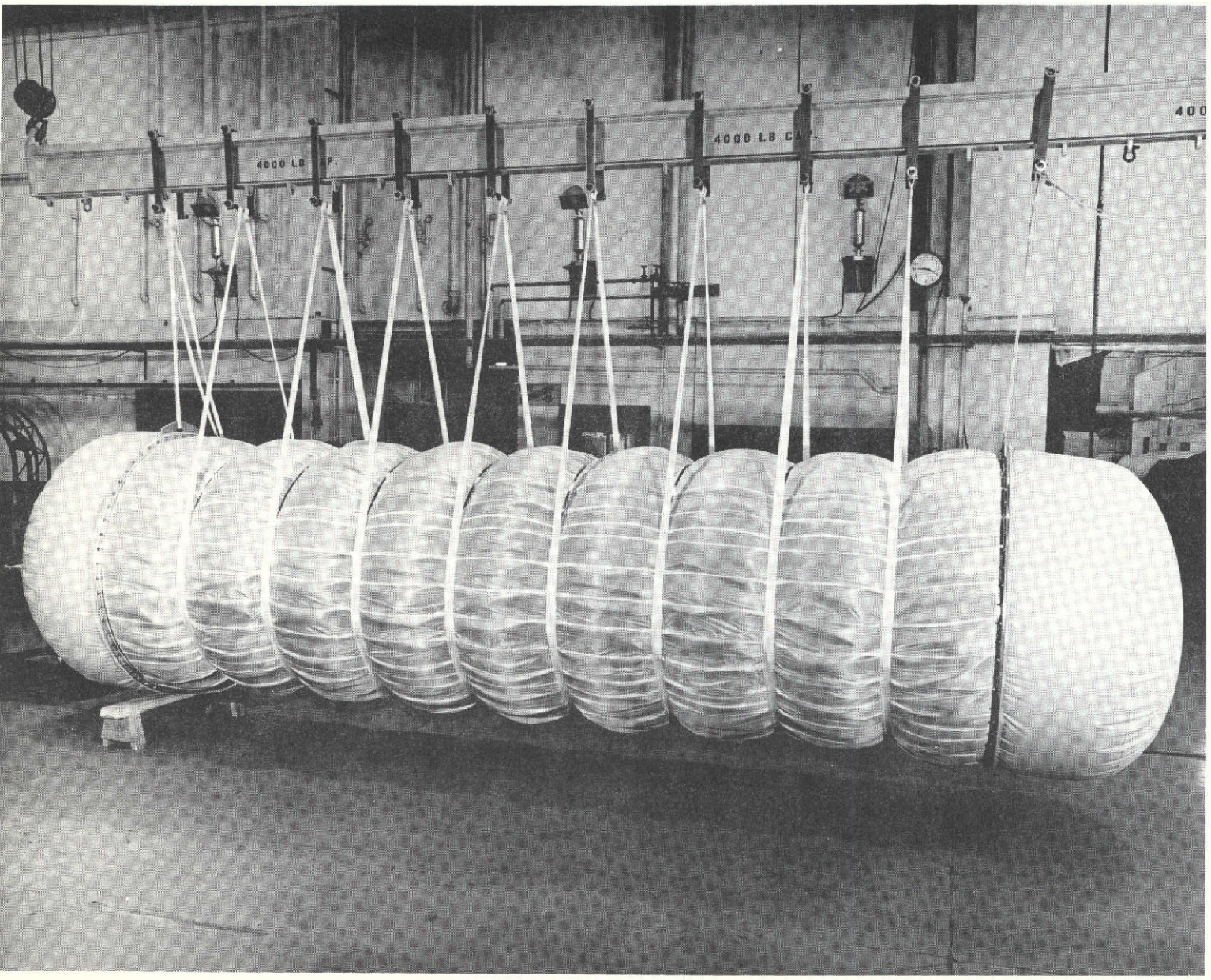


Figure 23. Full Scale Tunnel Fully Deployed
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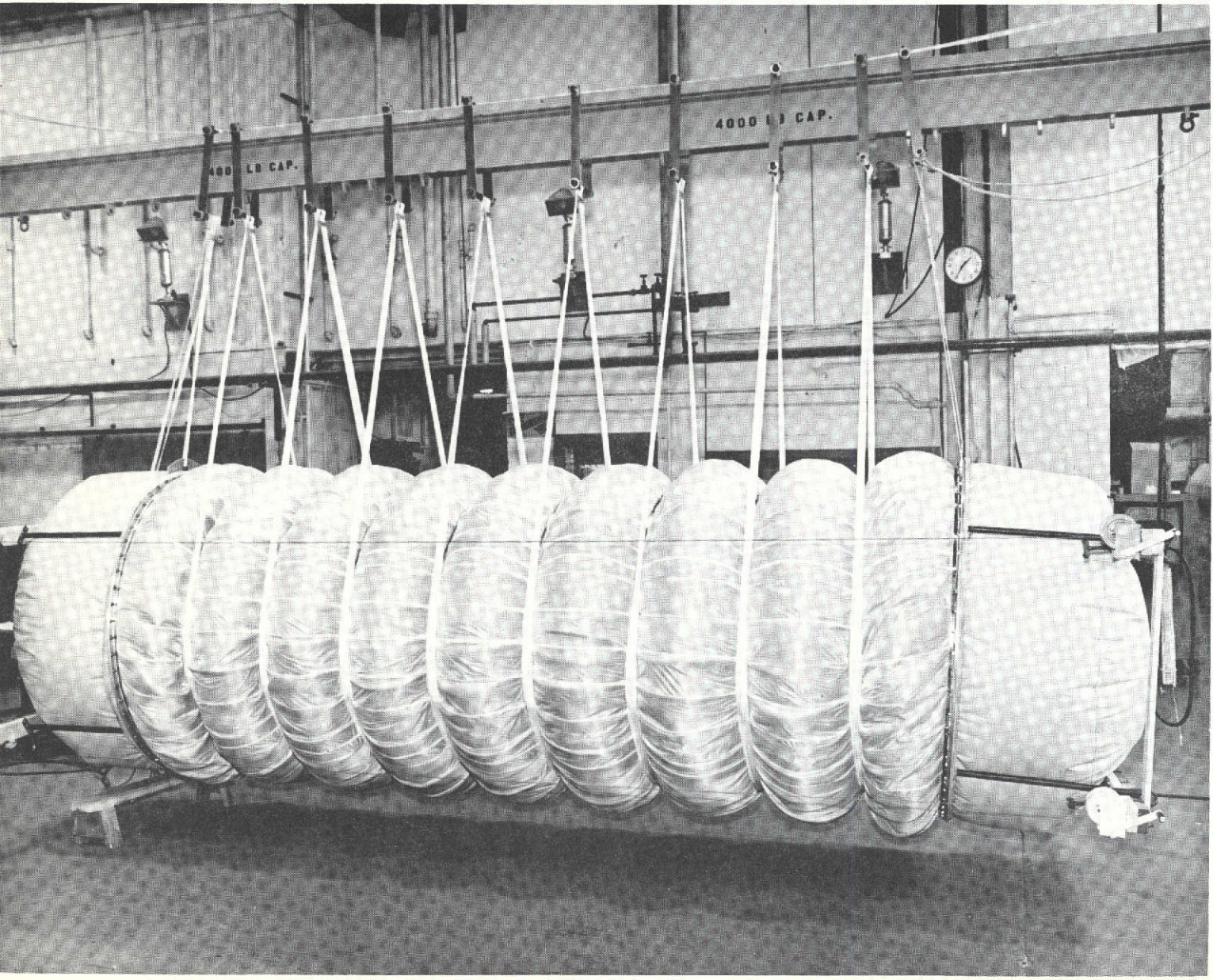


Figure 24. Full Scale Tunnel Partially Deployed
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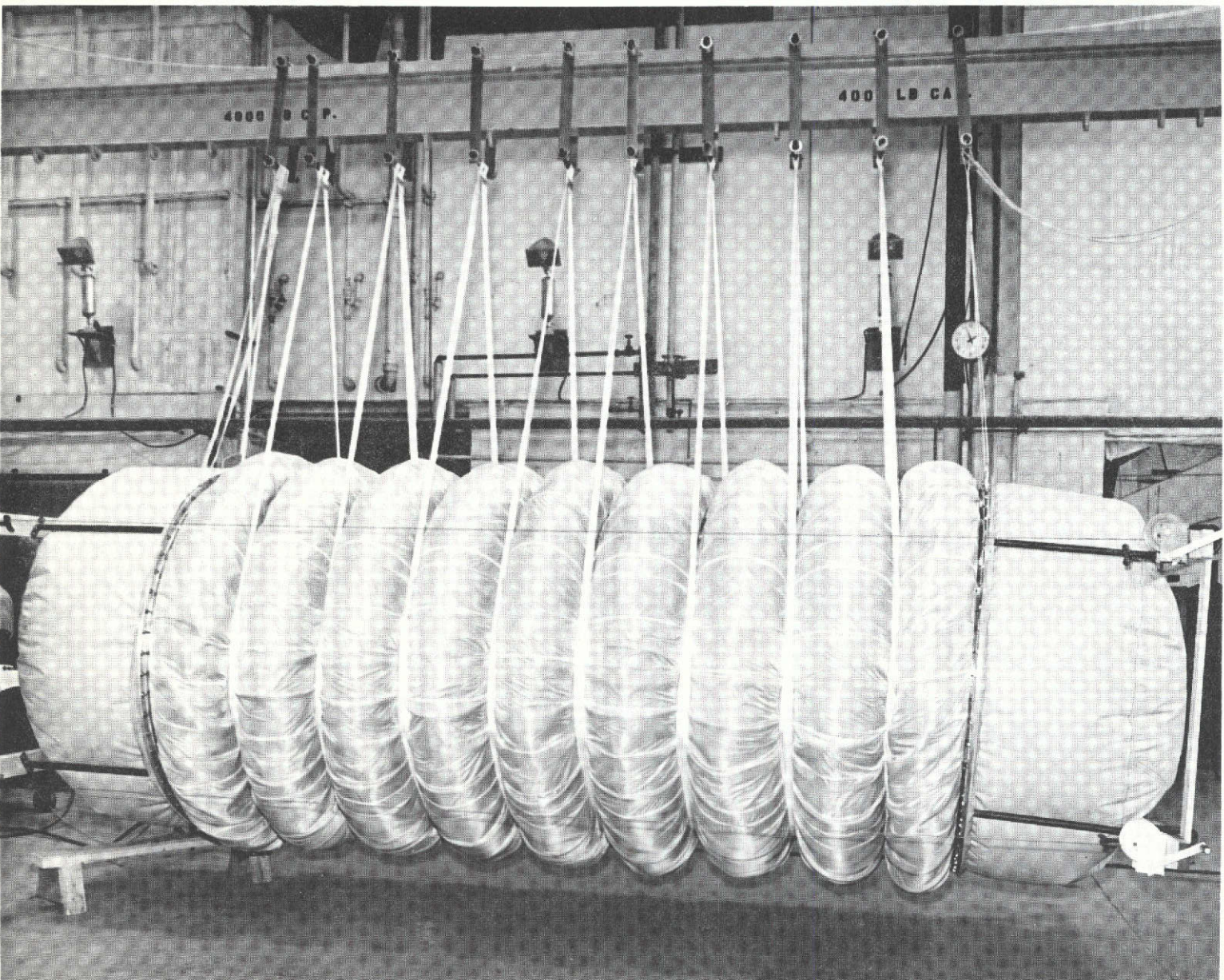
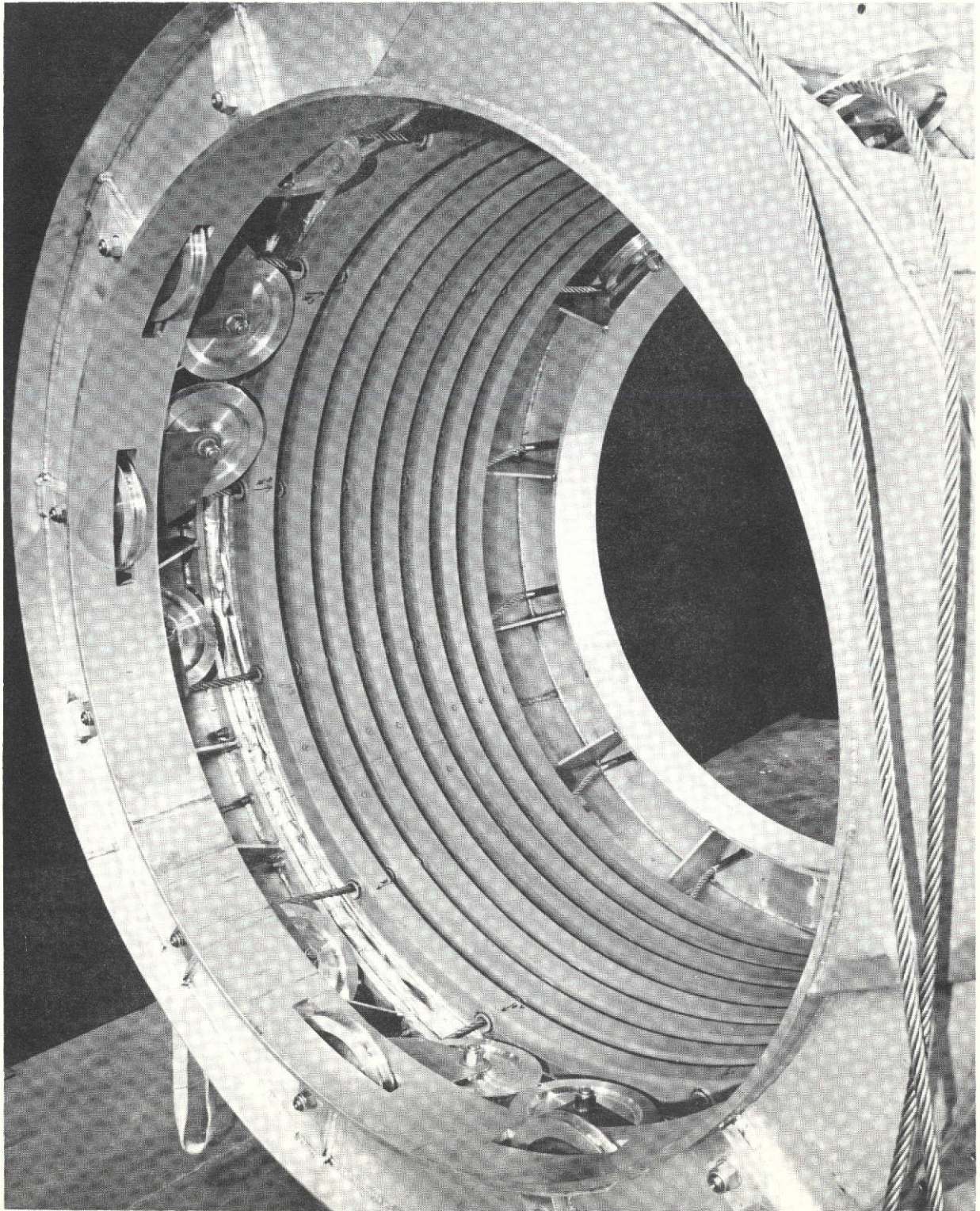


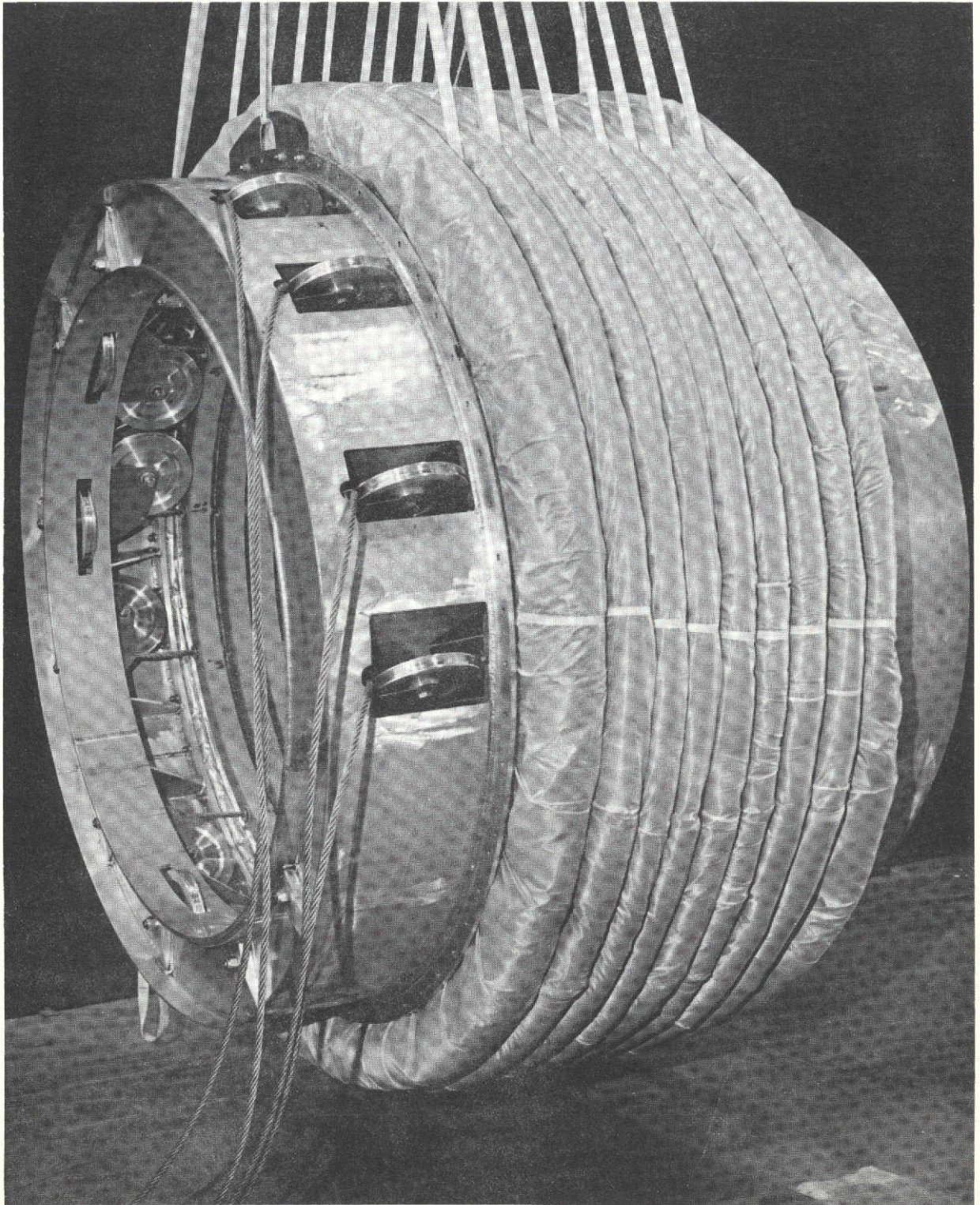
Figure 25. Full Scale Tunnel Partially Deployed



E-ID-115(7-71)
REF: EOI 380



Figure 26. Internal View of Tunnel in Packaged Condition



E-ID-15(7-71)
REF: EO1 380

Figure 27. External View of Tunnel in Packaged Condition

III. Conclusions and Recommendations

The flexible tunnel, as built, presented a minimum of problems in fabrication. The minimal testing performed at Goodyear prior to delivery was very encouraging with respect to the ability of the tunnel to perform as desired. It would be recommended that any future tunnels employ a fabric liner on the inside to protect against possible punctures. This liner could be added without a major redesign. It would further be recommended that the rings and clamps be manufactured from a higher strength to weight material so as to reduce the total weight of the structure. It is apparent that a flexible tunnel approach offers the distinct advantage of providing adjustability for various mission requirements in addition to providing a small packaging capability during launch or landing if required.

Goodyear recommends that the tunnel delivered to MSFC be tested per the Goodyear generated test plan to further evaluate the tunnel and bring to the surface any problem areas that could be avoided on any future tunnels.